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THE AUSTRALIAN INSTITUTE OF AGRICULTURAL SCIENCE

A. G. STRICKLAND

On January 22, 1960, the Australian Institute of Agricultural Science completed twenty five years of service, rendered not only to members of the profession which it represents, but also to the community, and particularly to those sections directly or indirectly concerned with the maintenance and development of Australian agriculture.

The record of service is not unchequered. Through youth and adolescence the Institute experienced many vicissitudes and at times it showed shortcomings. On the other hand, it has not lacked vigour, which when applied in the right direction, has been rewarded by positive achievements in a number of fields.

CONCEPTION

The idea of an Australian association of graduates in Agricultural Science was conceived in 1932 in initial discussions between Gerald de Vahl Davis and J. Leith Gillespie, graduates respectively of the Universities of Sydney and Melbourne. Then followed an ever-widening circle of informal discussions in several states. In August, 1933, Gerald Davis submitted a definite proposal for such an association, including a draft constitution to a meeting of the Sydney University Agricultural Graduates Association. There was unanimous agreement "that a federation of men and women interested in the profession of Agricultural Science in Australia should be formed, and that the Agricultural Graduate Society in each State should be invited to consider the proposal".

This was the beginning and the Institute owes a great debt to Gerald Davis, not merely for his part as initiator but also for months of subsequent toil in co-ordinating widely divergent opinions throughout Australia. His efforts were rewarded in January, 1935, when a meeting of twenty delegates from the Australian Capital Territory and all six states resolved to found our Institute and adopted a draft constitution.

INCEPTION

The inaugural meeting of the Institute took place a few days later and it is appropriate here to quote several extracts from the address then given by our first President, Dr. A. E. V. Richardson. He said, "For some time past, agricultural scientists in the Departments of Agriculture, the Universities and commercial organizations have felt the need of an organization, Commonwealth wide in scope, through which the views of the profession could be expressed . . . Twenty five years ago it would have been impossible to have held a meeting such as is gathered here tonight. At the time the study of agricultural science at Australian Universities was just be-

Mr. A. G. Strickland, Director of Agriculture, South Australia, was Federal President of the Australian Institute of Agricultural Science for 1959.

ginning. Today more than three hundred graduates are engaged in the task of assisting agricultural progress in Australia.

The main objectives of the Institute are to promote the advancement of Agricultural Science and to further the interests of agriculture in Australia; to encourage a national policy of agricultural research and the interchange of ideas between research workers in agricultural science; and broadly to promote the welfare of the profession and raise its status in the community . . . The major work of the Institute will be the development of an esprit de corps among the members of the profession throughout the Commonwealth, and in assisting in the formation of a public opinion which will insist that the agricultural and pastoral resources of Australia should be developed by the best known methods and utilised to the best advantage attainable.

In the field of agricultural research and its application to practice, members of the Institute will have great opportunities for rendering service to the community."

Thus did Dr. Richardson summarise the objects of the Institute as they were in 1935 and as they still are today.

DEVELOPMENT

Membership

Numerically the Institute quickly exceeded the Executive's anticipations. Ten months after inauguration there were 245 members; at intervals thereafter, gross membership, including student members, was 281 in 1936, 449 in 1940, 618 in 1947, 1058 in 1953 and 1754 at the end of 1959.

These figures reflect the steady growth which would be expected in membership of a body representative of an expanding profession like agricultural science. But is the increase as steep as it should be? Certainly it has been offset to an extent by the reluctance of many specialists in the agricultural sphere to become members of the Institute.

Recent amendments to the Articles now provide for admission to membership, as "Company Associates", any company or organization whose activities are substantially concerned with agriculture or agricultural science. The effect of this special type of membership on the overall membership figures will be disclosed progressively in the future.

A move to admit also to Associate membership non-graduates with a genuine interest in agriculture because they are farmers, agricultural journalists, bankers, or follow some other vocation allied to agriculture, was rejected by popular vote in 1959.

Branches

Increase in Institute membership has not so far been accompanied by spectacular variation of the original structure of centralized branches in Australian Capital Territory and each of the states. However, sub-branches have been formed to cater for the interests of groups of members situated in regions remote from capital cities.

This year an eighth branch has been established—the Papua and New Guinea Branch with a present potential of 50 members. The Institute extends congratulations and good wishes to members of this new branch. Council has already given assurances of all possible help, recognizing that relative remoteness from Australia and a widely scattered membership will present problems to the new branch.

Administration

In its early years the Institute was governed by a Council which included a Vice-President from each branch, as well as a Federal Committee comprised of delegates from each branch, at the rate of one delegate for every 25 members, up to a maximum of four per branch.

It was soon realised that a governing body of these dimensions was quite impracticable, and in January, 1937, Council was reduced to the three Federal office bearers and one representative of each branch. Provision was made for each such representative to appoint a personal proxy to attend meetings which he could not attend.

As the Institute grew, the load which fell on the Honorary General Secretary and other key officers of Council expanded rapidly. For nearly twenty years such officers bore the brunt of administration of the affairs of the Institute and few members today realise how great is our indebtedness to these people for their honorary activities.

Early in the 1950's with membership four times that of 1935, and increasing pressure for more positive prosecution of Institute aims, it was obvious that honorary officers, loyal and unstinting in their service though they were, could not carry the burden unaided.

In 1953 the then President of the Institute, Dr. A. R. Callaghan, negotiated a promise of financial assistance from the Commonwealth Extension Services Grant for the establishment of a Central Secretariat. Such a step necessitated amendment of the Articles of Association and there were many members who did not consider it a wise step. The Institute faced its first major controversial issue, but within twelve months a referendum of members sanctioned the establishment of a Central Secretariat.

Mr. J. A. Roberts was appointed Executive Officer in 1954 and some three years later the Institute acquired its own building in East Melbourne.

With a Central Office and a full time Executive Officer, Institute activity increased markedly. For the first time deliberate action was taken to inform the public of Institute affairs and of the function of the agricultural scientist in the community. Financial assistance was sought from industries associated with agriculture. In broad terms, the Institute became a national body instead of a loosely knit group of branches.

INSTITUTE ACTIVITIES

Exchange of knowledge

Throughout its life, and no less now than in the past, the most important activity of the Institute has been the exchange of knowledge relating to agriculture. This exchange goes far beyond the "interchange of ideas between research workers in agricultural science" cited by Dr. Richardson in his inaugural address.

Exchange of knowledge is largely a Branch function and at one time was domestic, even private, within each branch. It has developed progressively to embrace such activities as refresher schools and symposia or special meetings in conjunction with farmer bodies and industry.

Also the aid of the press has been increasingly enlisted in this exchange, both at Branch and Council levels. We have embarked upon the preparation of an Agricultural Note Book, now near publication, and a text book on agriculture, not so near.

It is not surprising that the widening scope of this particular activity has exerted a marked effect on the prestige of the Institute and the profession. However, this effect should be regarded as a secondary one which will operate to our full benefit just so long as we regard exchange of knowledge as a primary aim in itself.

Integration of the profession

Those concerned with the launching of the Institute twenty five years ago envisaged "a federation of men and women interested in the profession of Agricultural Science". The majority of members, then and now, comprises graduates in Agricultural Science. But in the intervening years the work of individual agricultural graduates has become increasingly specialised—a natural corollary of the organisation of expanding agricultural research and extension establishments in the universities, the C.S.I.R.O. and State Departments of Agriculture. When the Institute started all members professed to be agricultural scientists. Now, some tend to regard themselves rather as entomologists, agronomists, plant pathologists and so on. This development, expressing itself in the formation of various specialist societies, has caused some concern regarding Institute support by specialists.

On the other hand, in his Presidential Address of 1958, Dr. W. A. T. Summerville remarked that the fact that "agricultural scien-

tists" are a motley collection of specialists is the Institute's strength. He argued that no agricultural scientist could serve agriculture to the full without the stimulus of contact with workers in related fields.

There is a basis here for optimism regarding the effect of specialist societies on the Institute's strength, and it remains for our policies at Council and Branch levels to encourage, by every possible means, wide acceptance of the need for broad agricultural interests on the part of those who work in restricted fields.

As the agricultural scientist becomes more specialised and the specialist societies proliferate, the Institute must develop a new emphasis. It should aim to be the integrator of these many specialisations and attempt to weave the particular contributions and outlooks of the specialists into the broad pattern of general agriculture.

Recently the Institute's articles were amended to provide for affiliation of appropriate specialist societies. This innovation coupled with development of policies which recognize the particular needs of agricultural specialists in various fields will enable the Institute to discharge its clear duty of binding them within a common framework of agricultural scientists.

Salaries and status

One of the several Institute objectives stated by our first President in his inaugural address was "to promote the welfare of the profession and raise its status in the community". Members would be less than human if they did not, at least privately, regard this as a most important objective.

It is to the credit of the Institute that, whilst not letting this objective take precedence over the broader ones concerning the nation and the agricultural community, it has had continuous attention since 1938. Highlights were the Forster-Vasey survey and report in 1944-5 and the Williams report of 1958-9, but continuously for over 20 years salaries have been the subject of varied activity both at Branch and Council level. There can be no doubt that this activity has influenced favourably the general status and salary levels of members, but it would have achieved much less if it had not been accompanied by our various activities in fields removed from those of self interest.

To put it bluntly, indirect impact of the Institute on the community and its leaders will achieve more in relation to status and remuneration of Institute members than will direct action.

The affairs of others

An important task of the Institute, and of any other professional body is to bring its learning to bear on the affairs of appropriate sections of the community which are outside the profession. In our case the chief sections concerned are the farmers and their ancillary marketing and processing industries, the industries which provide the farmers with chemicals, machinery and other requisites and finally governments who are concerned with policy and legislation relating to the activities of the first two sections.

The first venture of the Institute in this field was the Potentialities and Population Survey of Australia suggested by Dr. Richardson in his Presidential Address to the first General Meeting. Although this project lapsed because of war-time demands on those involved, a great deal of information was assembled and much of it used to considerable advantage in post-war planning.

Another early project, the Plant Quarantine Report of 1941, reached a most successful conclusion as most of its recommendations were acted upon by the Commonwealth Department of Health.

With varying energy and variable outcome, the Institute, either as a whole, or at Branch level, has engaged in an imposing number of projects concerning the affairs of others. Reference to issues of the Institute Journal over the years shows that these activities relate to a remarkable spread of topics ranging from agricultural economics to agricultural engineering, from submissions to the Prime Minister on Australian agricultural policy to recommendations to the Murray Commission. Major pro-

jects in which all branches participated, and some of which extended over many years, approach twenty in number and only three of these were of purely domestic concern to the Institute and its members. Most of the projects were in fact practical efforts "to promote the advancement of Agricultural Science and to further the interests of agriculture in Australia". They involved reports and submissions to Government Departments and Ministers, to the Australian Agricultural Council, to Universities and to various Commissions.

In some cases the submissions apparently achieved little or nothing; in others, they led to concrete results. Broadly, it is true that many forward moves in the interests of Australian agriculture gained their initial momentum as a result of Institute action.

Institute activity concerning the affairs of others has not been confined to investigation, exploration and the submission of reports and recommendations to governments and organisations.

There is another most important phase of this activity—our contact with the farming community and with the secondary industries which service the farmers. Development here has been considerable. First through the medium of special "open" Branch meetings, then through increasing use of the press and radio, and latterly by arranging symposia and refresher schools of interest and value to primary producers and industry folk, we have established a large and expanding association with these sections.

THE PRESENT AND THE FUTURE

At twenty-five years of age the Institute has reason to be proud of its achievements. It is a sizeable body which alone represents the profession of Agricultural Science in Australia. It is recognized by the community, by governments and by organisations as an authoritative reference body on agricultural matters. Considered Institute opinion has often guided policies concerning the welfare of agriculture. The Institute has been allotted specific tasks relating to Australian agriculture, as instanced by its responsibility for conduct of the new scientific journal sponsored by the Australian Agricultural Council.

It has established ties with the farming community and its ancillary industries.

In looking forward it should be our earnest hope that the Institute will increasingly influence the policies and practices relating to agriculture in this country. This it can do by facilitating exchange of agricultural knowledge, by providing a moot for the rapidly increasing body of specialist agricultural workers and by offering well considered and unbiassed views to those responsible for framing agricultural policies.

Sound service in these fields is a basic necessity if the Institute is to secure for its members adequate facilities and just reward for their important work.

THE INSTITUTE JOURNAL

R. N. SANDIFORD

The Journal of The Australian Institute of Agricultural Science first appeared in March, 1935. This makes it one of the oldest features of the Institute. Only the Constitution and the Executive Committee are older. The Journal itself preceded the Federal Council and the branches in all states. This unique situation came about when, at the inaugural meeting of the Institute, the N.S.W. delegates offered to hand over as a going concern the journal *Suaga,* which had at that time been published for some eight years by the Sydney University Agricultural Graduates Association. It was a generous offer and for the Institute a very fortunate one. It gave, right from the start, tangible evidence that the Institute was in there doing something. The release of the first issue in March, 1935 may well have influenced the meetings later in that year when the states set up their branches.

Through fifteen to twenty of the next twenty-five years the Journal was for the average uncommitted member synonymous with the Institute. It represented his contact and source of information on all matters Institutional. It was something in the hand for the subscription out of pocket.

Over the last seven years, while the Journal has expanded in size and stature as never before, it has, paradoxically, declined in importance as an Institute activity. Today for all but the marginal members it is only one of several activities. Its cost as a percentage by total Institute expenditure has declined from 40 per cent. in 1952 to 12 per cent. in 1959.

SOME HISTORY

With the Journal in 1935 came the previous editor of *Suaga,* H. J. Hynes who was to set a record term as editor (1935-41). A term that has not since been approached. Hynes' achievement is best summed up in the Report of Council for 1938 where it is recorded. "This publication has been the creation of Dr. H. J. Hynes. . . .". Any attempt to subdivided the twenty-five years must take as its first period "The Hynes Era". In those seven years the Journal was consistently good and getting better. It was not to be matched again in size until 1953. Looking back from 1960 the volumes of the thirties seem much closer to us than those of the forties. At times only the advertisements and the balance sheets betray the date.

After Hynes stepped down came a period of troubles with a phase in each of New South Wales, South Australia and Victoria. The war, post-war shortages, and industrial troubles, were largely to blame. Potential contributors were fully occupied elsewhere. Yet this time, when the Journal was by objective standards at its weakest, was possibly its greatest period of service. All other Institute activities were at a low level. Certainly as I remember the latter half of the period the Journal was the Institute.

By one of those happy coincidences of circumstances and personalities W. P. Dunk

Mr. R. N. Sandiford has been Honorary Editor of the Journal of the Australian Institute of Agricultural Science since 1958.

took the editor's pen just as the Journal and the Institute were ripe for expansion. The war and the post-war shortages were behind, membership was increasing, the moves for a central office were under way, the first of the post-war graduates were beginning to write.

By example, plea, and organization, Dunk created the Journal we know today. The features that he added or revived include news items, talks, thesis summaries, the offices of news editor and associate editor. These innovations were matched by an expansion of all sections of the Journal. In 1952 the Journal was 230 pages, in successive years up to 1958 the figures were:— 270, 270, 290, 330, 380, 410.

Even as this expansion started factors were working, some of them due to the expansion itself, to reduce the role and relative importance of the Journal. Other Institute publications began to appear, cutting into the Journal's traditional territories. The very size of the Journal was, by 1957, threatening to overwhelm the staff. The rising cost was becoming an embarrassment to a council increasingly committed to other and new activities. And all the while research papers and notes came forward faster than our capacity to publish.

CONTRIBUTORS AND CONTENTS

In figures the Journal of the Australian Institute of Agricultural Science has now printed 99 issues, missing only three issues in 25½ years. It has run to 6,000 pages and carried just over 1,000 original contributions. These figures are mere bones. Yet, given the volume of material published and the space available here, there can be little more than bones and a few impressions.

The contributors to the early issues now read like a Who's Who of Australian Agricultural Science. Thus in volume 1 number 1 we find—J. A. Prescott, G. de V. Davis, A. J. Nicholson, R. J. Noble, S. Fish, E. Meeking, K. J. Bailey, H. C. Forster, N. S. Noble, H. C. Trumble, E. T. Edwards, F. M. Read and C. E. Cole, F. G. Holdaway, and H. J. Hynes. Can we promise such a future to those contributing now? By the end of the third volume in 1937 seven of the contributors to this Jubilee issue had published in the Journal.

It is of some satisfaction that a small but significant portion of the work that has been singled out by the other contributors to this issue was published in the Journal. The reference *J. Aust. Inst. Agric. Sci.* is now common currency in both Australian and overseas journals.

The hundreds of reviews published, some of great merit, can only be looked at as a whole. To attempt to distinguish here would be unfair and unwise. As a whole they present a formidable achievement, and anyone who spares the time to read, or re-read, all or a large portion of them obtains a view of the whole field of Australian agricultural science not to be found anywhere else.

The role of the Journal in recording the doings of the early Institute years is commented on below. For the mere reason that it still exists the record is invaluable. Alongside this record of facts there runs a complementary record of the thoughts and plans that have moved and shaped, or sometimes failed to move and shape, the Institute. In the Presidential Addresses, in some articles and in the "Why won't the Institute . . ." letters we can trace the plans that came off and those that misfired.

A. E. V. Richardson's President's Message in volume 1 number 1 and Presidential Address in volume 3 number 1 have long been guides to the Institutes development, as have the many articles by G. de V. Davis. In years to come the Presidential Addresses of H. C. Forster in 1957, and W. A. T. Summerville in 1958 may be regarded in the same light. Whether their addresses were blueprints or prophecies does not matter and is hardly worth the solving. What matters is that what they proposed is increasingly, though slowly, coming about.

No view of contents however brief could close without another mention of H. J.

Hynes. He alone amongst the editors had the time, courage, and ability, to turn out a series of editorials; editorials that still read well, that covered a diverse range of topics, and that contributed no less than the Presidents' statements, to the shaping of an Institute viewpoint.

THE JOURNAL AND THE INSTITUTE

For many years the Journal was the Institute's only publication. Its charter ranged beyond reviews and research papers, news items and personal notes. It carried lengthy council reports, notices of meetings and amendments, balance sheets and budgets. It is a tribute to the editors and sub-editors of the time, but a sad comment on others, that the only records remaining of many of the activities of the first ten years are those printed in the Journal.

Yet despite this testimony the Journal has never been a really suitable place for carrying such matter, or even for personal notes and branch notes. The inevitable delay between writing and publication in a quarterly is fatal to news. So it was not surprising that during the fifties a new series of Institute publications arose to usurp the "Institute Affairs" function. First South Australia, then the other states, started to publish news bulletins. They varied from state to state and from time to time in size, quality, and regularity. They took over the material that the Journal could not handle as well as material that it did handle. Although the sections have been maintained in the Journal their size has shrunk, particularly since 1957. The establishment of a central office produced a new and powerful centre for despatching paper. Council reports and budgets, balance sheets and Presidents' messages went straight to members. Personal circulars proved a much more efficient and remunerative way of handling positions vacant than an advertisement in the Journal.

The fifties also saw the Institute embark on publications of rather different kinds. This was done both at federal and branch levels.

In the early fifties the idea of a Notebook and a Textbook was conceived. As I write, the galleys of the Notebook are going back to the printer. Birth is not far off. The Textbook is further away. The proceedings of various conferences, symposia, and schools, are now being published in their own right. The most noteworthy is the series of Western Australian Joint Institute — Farmers Conferences in 1958, 1959 and 1960. Finally there are the prestige and propaganda publications highlighted by the splendidly produced *Agricultural Scientists in Australia*.

Ten years ago all these things would have been published in the Journal, if anywhere. Their publication elsewhere has kept the expansionary pressures on the Journal within limits. If they are overlooked, and they often are, the growth of Institute publication seems much less than is actually the case.

THE AUSTRALIAN SCENE

It is hard to realise that the Institute Journal is, of the journals now publishing agricultural science for agricultural scientists, the second oldest. Only the specialized *Review of Marketing and Agricultural Economics* is older. The Journal started in 1935 on the twin planks of serious reviews and short research papers, it has maintained these, sometimes in uneasy harness, to today though changes are now in sight.

The field of serious scientific reviews of agriculture has been left almost entirely to the Journal. It is a feature of our times that official funds have been readily available to sponsor journals publishing research reports yet rarely for those undertaking the equally important task of review, synthesis, and criticism. This latter task has been left almost everywhere to the professional associations and learned societies.

In 1953 and for quite some time afterwards the journals of the State Departments of Agriculture carried research papers. They have now largely ceased to do so and have become farmers' magazines. *The Journal of C.S.I.R.*, which was the other major Australian opening for agricultural science papers in 1935—

though it was far from being exclusively agricultural science—has ceased publication.

Since 1935 a crop of new journals have come into existence: *The Australian Veterinary Journal* in 1938, *The Queensland Journal of Agricultural Science* in 1944, *The Australian Journal of Biological Sciences* in 1946, *The Australian Journal of Agricultural Science* in 1948, *Quarterly Review of Agricultural Economics* in 1950, *The Journal of the Australian Society of Agricultural Economics* in 1957, and the *Proceedings of the Australian Society of Animal Production* in 1956.

Despite all these new outlets, and the fear that was expressed for our own future as each one was announced, neither the Journal nor the others have been able to keep pace with the volume of research papers offering. In a further attempt to cope with the outpouring the Australian Agricultural Council has entrusted the Institute with the publication of a new journal of experimental agriculture and animal husbandry.

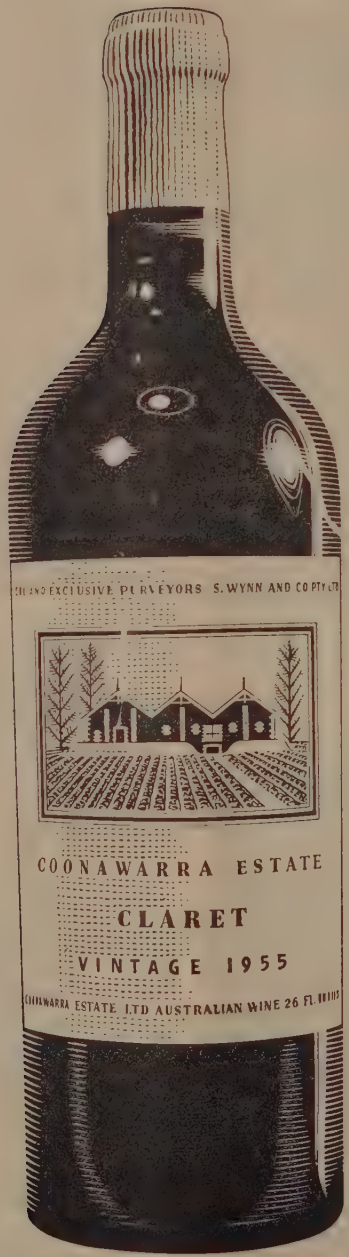
PAST POLICY AND THE FUTURE

The Publications Committee has always been chary of making statements about its principles and aims. But by reading through their meetings it is possible to discern two very important principles that have shaped the Journal, at least for the past twelve years. Repeatedly in actions though rarely in words a policy of readers first has been implemented. There has been no talk of supplying publication opportunities though great opportunities have been supplied. Also there has been no false notion of pride and prestige about what the Journal should or should not publish. If for policy reasons other journals will not touch a particular contribution the Publications Committee has seen it as a fitting function for the Institute Journal to look at that paper in the light of its own needs. This is a far different thing from accepting papers rejected on quality grounds by other journals. The distinction is apparently not clear to many members who fear that the Journal will become the last resting place for tattered papers.

Bringing these two principles together a policy emerges that is something along the following lines. If someone else will publish it well and good; our funds are limited. If no-one else will publish it and if we believe it is in the readers interest (the readers being the members of the Institute) that it be published then we will carry it. This seems to me to be a completely desirable policy for the profession's own journal both now and in the future.

The new journal of experimental agriculture has been set up to publish research results. The Institute Journal will not compete —indeed to do so would be courting the role of the cuckoo's mother. It seems now that the result of not competing will be that we will lose all technical papers. The judgement may be premature. Seven other journals have not forced us from the field. Will one more succeed?

It is fortunate, and not a matter of regret, that the publication of serious reviews will be the major role of the Journal as it moves into its second twenty-five years. There has been no challenger to our position in publishing these reviews nor are there any in sight. Yet, compared with the reasonably well developed machinery for publishing research papers, review and criticism are the weakest facets of the Australian agricultural science literature. The reason is possibly that research papers create their own pressure for publication and bring their own rewards to authors. On the other hand reviews give greater rewards to the readers than to the writers and their generation is far from spontaneous. However, and the evidence is in the following pages, many members have shown a capacity to labour long in response to our request that they enlighten their fellow members. The Institute debt to the hundreds of men and women who have contributed over the years is immense. If we can continue to run up debts of this nature the future of the Journal is secure.



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AGRICULTURAL SCIENCE IN AUSTRALIA 1935-60

A report of trends, highlights, achievements, and prospects in the agricultural sciences in Australia during the past twenty-five years.

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FARMING AND SCIENCE

S. M. WADHAM

A very well-known member of the Institute once remarked in the course of conversation: "I do hate history." He was a specialist in an applied science and his remark made me realise that the way in which he and I had learned history at school—kings, battles, Acts of Parliament and all that—justified his remark from the point of view of a scientist. But to an agriculturist history means much more. It includes the economy and social background of the farm population, their attitude towards governments and towards authority in general, the extent to which they feel they are a part of the nation or a neglected minority, the importance of improving the volume of production having regard to the availability, or otherwise, of markets, the capacity of science to overcome farmer problems without corresponding increases in their costs, the effects of government policies towards land tenure and land settlement and towards farming in general, the availability of credit, the organisation of the farmers both politically and economically.

Each of these factors changes as time marches through each decade, but they are the most important influences on the agricultural position during most periods. Consequently, any review of the period, 1935-1960 must be prefaced by some survey of the position of Australian farming during the 1920's and in the economic cataclysm of the depression which developed in the early 1930's.

THE EXPANSIVE 1920'S

World War I was followed by a wave of agricultural optimism in all countries where farming is important. The high prices of the war period stimulated plans for the development of farming in areas as wide apart as Australasia and Canada, or Manchuria and South Africa. In our particular zone this optimism was seized on by politicians as an easy method of solving the problem of employing effectively the ex-service men. And so land settlement schemes were the order of the day in every state and every industry. Each mainland state opened new areas for wheat farming and equipped them with new railway lines, roads, schools and other amenities. Forests were cleared for dairying in Gippsland, in many of the river valleys and tablelands of coastal New South Wales and Queensland and in north-west Tasmania and the wetter parts of the south-west of Western Australia. New irrigated areas were opened in the M.I.A. and at Redcliffs. Land was cleared for orcharding in various districts and large properties were

sub-divided for returned servicemen in many areas.

In the middle 1920's this initial post-war burst of expansion was continued with a scheme for migrants from Britain. Finance for nearly all of it was raised by loans floated in London by the various states. But halfway through the decade the prices of agricultural products on the world market were falling and the new settlers were having difficulty in meeting their financial commitments. Conferences were held and politicians began to turn to scientists to solve the problems by overcoming the technical difficulties of the farming industries.

Before that time the only scientific research related to agriculture in Australia was carried out by such members of the staffs of Departments of Agriculture as could be spared from the regulatory and advisory services and by a few people in the universities, all of which were starved for funds. The exception was the endowment of the Waite Institute at Adelaide. Trying to prepare an address on Science in Agriculture in Australia in 1926 the only items of progress the present writer could discover were the work of the plant breeders on wheat, some small items of progress in the veterinary field, and the manufacture of superphosphate. These were not a large contribution by science to the assistance of the farming industries,

The C.S.I.R. was founded in 1926 and at the same time the Development and Migration Commission was set up to analyse the prospects of each proposal for further expansion. It had to reject nearly all the suggestions made by the various states because the rising level of costs and the falling levels of the prices of most agricultural products had made further development quite uneconomic.

It is easy to criticise the leaders of this period and to suggest that the circumstances were similar to those of the present time. in which the worst calamity has so far been avoided. But certain changes of the utmost significance have taken place during the intervening period. In the 1920's gold still formed the basis of the currency; the amount of credit available and its relationship to the gold held was the "gold standard system". Taxation was relatively low so developmental works were mostly paid for out of loan money and not from taxation which has provided for so much of the money for many Commonwealth projects in the 1950's. Further, the general trend of financial control during the 1920's was deflationary, the most unfortunate example being Britain's untimely attempt in 1925 to re-establish the prewar parity of the pound at 4.82 $ U.S. The crowning economic stupidity was perhaps the increases in the American tariff which virtually prevented her late allies from paying their debts to her in the only practicable way — the export of goods to U.S. markets.

All through the 1920's farmers had been finding it more and more difficult to meet their rising costs. Marketing schemes were organised to avoid some costs of selling and also to check cut-throat competition on the Australian market. The Paterson plan for dairy produce was the widest of these, the sugar agreement was the most sensible, and was only possible because the few sugar mills in New South Wales agreed to market their sugar through the Queensland Sugar Board—the output of the sugar beet factory in Victoria was so small that it could be ignored. Generally Section 92 of the Constitution was the great stumbling block. But overseas marketing could be controlled by Commonwealth Boards because overseas trade is constitutionally a Commonwealth function.

THE DEPRESSED THIRTIES

Generally the countryside was becoming depressed and although some steps, e.g., improved wireless and telephone services, were taken to decrease its sense of isolation, the feeling of frustration spread. The high promises of the early 1920's had not been realised, and such supports as the countryside did receive through cheap rail freights were seldom recognised. State governments had advanced many millions for land settlement and were expecting interest and amortisation payments to be made although the bushel of wheat and

the pound of butter fat were worth less than when the expansive schemes were planned. Many farmers were unable to meet their creditors — apart from the governments of their states.

The 1930's were ushered in with some wheat being sold as low as 1s. 6d. per bushel at the sidings, butter fat in the flush season was sometimes as low as 7d. per lb. The average price of the wool clip of 1931-3 was only 8.97d. per lb. Unemployment was general in the cities and was added to by men leaving employment on the farms, or even walking off their own properties. Hostile demonstrations occurred in some areas of recent settlement, one or two farmers threatening to shoot anyone attempting to enter their farms. In some marginal wheat districts on the west coast of South Australia the chief item of cash expenditure on many farms was for tea. The farmers felt that the cities were hostile to their interests. They often had similar feelings towards the country towns where they owed large amounts to the storekeepers. They no longer believed in the politicians and the country party emerged into local prominence, although its inability to solve quickly the rural economic problem soon reduced the enthusiasm of many of its supporters.

This was the background of farmers' thought against which scientific investigation began to emerge as a possible aid in meeting a desperate economic situation. Fortunately several notable successes had already been scored. The sensational suppression of the prickly pear by *Cactoblastis cactorum* was widely publicised, while the capacity of plant breeders to provide more effective races of wheat had been appreciated since Farrar's work at the beginning of the century.

Carbon tetrachloride was already assisting in the control of fluke and copper sulphate was being used in appropriate places towards the same end. Superphosphate was used fairly generally in many southern wheat areas, but only in Western Australia in large enough quantities to raise rapidly the soil phosphate to the levels required for leguminous annuals. Fallowing was frequent in many wheat districts, ostensibly for the conservation of moisture, but, as work at the Waite showed, its effect was largely due to the accumulation of nitrate in the soil and to the suppression of the weeds which would have absorbed this nitrate. The Soils Division of C.S.I.R. had set out to recognise and classify the soil types of the continent. In particular it had made detailed surveys of the soils of some of the irrigation areas. By the middle of the 1930's these surveys were beginning to be of value in preventing further additions to the list of past disasters due to unsatisfactory irrigation schemes and faulty methods of applying the water. During the early 1930's work on pastures had begun, especially in Victoria, where, as the government was unable to find the money for investigations, various firms interested in fertilisers, dairying and seeds provided money to form the Victorian Pasture Improvement League, which financed work done by departmental officers. By 1935 the C.S.I.R. had established many of its divisions which were specially interested in research connected with problems of farming and land use. These had been collecting their staffs and had been setting out on sundry researches some of which bore fruit in later years. The sugar industry, through its range of experiment stations and other laboratories, was probably the best organised rural industry from the technical viewpoint at that time.

The Commonwealth budget of 1931 altered the prospects of the tobacco industry by giving Australian manufacturers a stimulus to use more of the local leaf in their products. The result was an increase in the acreage planted in 1931-32, but exceptionally heavy attacks of

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blue mould ruined many crops and disheartened many growers, who were already becoming aware of the fact that tobacco is not an easy crop either technically or in its labour requirement.

By the middle 1930's when the proper part of this survey begins, the economic position of the various industries had improved very little. The price of wool had increased a little, wheat was still only about 3s. per bushel and butter fat usually below 1s. per lb. Meat animals were selling very cheaply. The Ottawa Conference had produced hopes but had only been of real value to dried and canned fruit producers and had eased the situation as regards meat. But a definite improvement had taken place in the minds of farmers, in that they now realised that they were to receive some special consideration. The devaluation of the Australian pound, the series of moratoria, the setting up of the Wheat Commission, and the prospect of a wide scheme of debt adjustment, all assisted producers in the export industries and gradually led to a return of confidence.

The depression brought about certain changes in some industries. It led to an increase in the number of farms producing butter fat, because the monthly cream cheque was a means of providing a little ready cash. The establishment of milk boards for regulating milk supplies to some cities ensured that at least this section of the dairy industry was on a reasonably economic basis. The wheat industry was given a home consumption price which in the average year increased the overall price of wheat at sidings by about 5d. per bushel. The Commission recommended all wheat growers to pay more attention to keeping sheep. The use of superphosphate for pastures was subsidised by 15s. per ton, which brought the price down to about £3 per ton at sidings and encouraged many graziers — small and large — to try "pasture improvement" by the removal of the commonest deficiency of the soils in the southern half of the continent.

This development was the most important change in farming outlook for many years. The average farmer did not think in terms of "the plant nutrients in the soil-pasture complex". He regarded supering solely as a new means of making his pastures carry more stock. But gradually the idea of changing the plant components developed, also the thought that soils might be deficient in other elements, and, if so, other additions might be valuable. Some firms preached liming throughout the moister districts, but in most areas farmers failed to find the responses induced by lime were lasting. Nitrogenous fertilisers had been advocated strongly in the early 1930's but were too expensive for pastures at that stage.

By this time wheatgrowers in some districts were finding under the wheat-fallow rotation, an ever-increasing difficulty in preparing their fallows for wheat. This meant late sowing and diminished yields in many seasons. The demonstration of the virtues of ley farming by workers at Rutherglen Experimental Station offered a remedy, but its wider adoption was not satisfactory in many districts until legumes (e.g., Bacchus Marsh 'sub') with shorter growing periods had been isolated and their seed had become available commercially.

The depression gradually stimulated a policy of providing public works instead of unemployment doles. This opportunity was used to install bulk handling systems in Victoria and Western Australia and to extend that of New South Wales. An underground drainage scheme was put down in the Mildura irrigation area. Irrigation techniques were improved in many districts. Schemes for the reclamation of salted land were developed. Collectively these developments may be likened to gropings of a semi-scientific character towards the central problem of improving the understanding of our soils and their complexities. They were a marked departure from the earlier popular belief that Australian soils were inherently fertile and lack of rainfall was the only obstacle to higher standards of farming. This may seem trivial, but it was important because it made farmers ready to try new methods and to appreciate that science might be of some value to them, not only in such sensational cases as the control of pests and diseases, but also in the humdrum techniques of cultivation and crop production.

Two bad seasons in North America reduced the world wheat surplus and the price rose sharply in 1936. At once farmers and serious business men talked as if the problem of the surplus was solved. Optimism was engendered, the Australian acreage under the crop rose in 1937-38, but by 1939 the surplus had reappeared and the price fell again. The lesson of overproduction had not been learned, farmers still thought their function was to produce as much as was conveniently possible; that it was the job of someone else to buy the produce and if the price became too low it was the government's duty to support by a marketing scheme or other service; alternatively some had more sinister views involving a conspiracy of city organisations and especially of overseas buyers.

WORLD WAR II

By 1938, European countries were becoming apprehensive and quietly importing reserves of raw materials; prices rose accordingly. When the outbreak finally occurred the Australian Government announced the Empire plan for dealing with the wool situation. The overall average Australian price of 13.4375d. per lb (greasy) was rather higher than that of the ruling market and inspired the confidence of the pastoral industry. On many properties it was easier to keep sheep than to do anything else, so sheep numbers increased steadily, and as the stocks of unsold wool accumulated storage sheds were erected in many centres to house them. The wheat industry harvested a record crop of 210,000,000 bushels during the first six months of the war, and as the silo system was incapable of storing it, large "temporary" dumps were erected at appropriate points. As shipping was not likely to be available for full crops during the war, attempts were made at rationing the acreage to be sown. In addition some of the areas which had proved economically marginal in the past were gradually weaned towards grazing; farmers who chose to leave being relieved of their debts to the Crown and provided with a cash bonus. The year 1940-41 was a drought in many wheat areas and reduced the surplus. Farmers were encouraged to use wheat as stock feed, especially for pigs.

Although the Commonwealth Government at first gave no lead to the major industries, it did stimulate the production of flax under an agreement with the British Government. Unfortunately, accurate information about the conditions for the successful cultivation of the crop was scanty and in many districts where it could be grown water supply was not sufficient to permit water-retting, so many factories were erected in districts where the uneconomic system of dew-retting had to be employed. Attempts were made to grow certain other crops such as navy beans, which had previously been imported, mainly from central Europe. Opium poppies and guayule rubber were also tried. New cool stores were erected to hold frozen dairy products and meat awaiting shipment.

The unfortunate occurrence which undermined the confidence of pig producers was the vacillation in the British demand for overweight pigs. At first Australian pigmen were asked to grow these in increasing numbers; later the plan was suddenly changed and producers found themselves with large numbers of oversized animals on their hands. A few months later the original demand was reinstated; by this time the processors had bought the surplus in at very low prices, and rumour had it that they were held in cold storage. This kind of treatment did not inspire confidence.

THE SECOND PHASE

The entry of Japan into the war and the bombing of Pearl Harbour altered the Australian situation completely. American forces were based on Australia for a time and it was important to supply them locally as far as practicable. Our own forces overseas were also expanding in numbers. These developments were a great drain on the manpower of the country-side so that all sorts of readjustments in farm management became necessary. It also led to the stimulation of certain forms

of production through the attractive contracts which became available for vegetables for canning and dehydrating.

The chief result of the manpower shortage was an intensification of mechanisation which first affected the dairy industry. Hand milking gradually disappeared. Secondly, when tractors were available they replaced horses, especially in the wheat areas. The labour shortage was probably worst in Queensland where the sugar industry began to find the organisation of the harvest difficult. The vegetable contracts hit the smaller dairy farms and the Maffra sugar beet factory found it difficult to obtain supplies because its contracts were less remunerative. The wine industry which had had difficulty in disposing of its product now found its output was scarcely equal to the demand.

The Agricultural Committees which were set up in districts served a useful purpose in channelling supplies of machinery and other agricultural requisites to the points where they were most needed. Probably their greatest effect lay in the stimulus which they gave to agricultural thought. The farmers realised that there were local bodies watching their interests and trying to help them—they were no longer a forgotten section of the community.

The drought of 1944-45 was a disaster of the first magnitude. The sheep population had reached 125 million in 1942, largely because of the low labour requirement for looking after sheep under our systems of management, and also because the fixed price of wool made growing it payable and a reliable proposition in many areas. But reserves of fodder were low, the transport system was taxed to the breaking point under the strain of military demands. Two drought years in succession led to a reduction in the sheep numbers to 96 million in 1946-47. Grain farmers were equally affected in many districts and dairy production was also reduced. Reserves of grain and other produce were consumed by the local population and on the farms, so Australia had little opportunity of playing much part in supplying the needs of war-torn countries struggling to avoid starvation.

POST-WAR RECONSTRUCTION

The end of the war found Australian farmers ready to do their best to assist in the much-publicised campaign for growing more food, but they were frustrated to find that they lacked the resources to play such a part. Labour was scarce; machinery and fertilisers rationed; the flocks and herds were diminished by the drought; the equipment of their farms had run down; fencing was poor, buildings dilapidated and pastures showing the effects of drought — and of diminished supering in some areas. Further, when they tried to get supplies of materials for making good the dilapidation they found they were competing with equally important demands for housing, schools, hospitals and factories and also for the necessary expansion in the basic industries of coal, iron, cement, timber and bricks.

Progress was slow and by 1951-52, Australia's trade balance becoming adverse, popular attention was drawn to the decline in volume of farm exports compared with before the war. So the Australian Agricultural Council set up a series of targets for a five year plan. Simultaneously the supplies necessary for reinstating farm equipment became available and most of the targets were reached in four years.

The war-time emergency had necessitated government support for many industries. The war-time accumulation of stored wool was taken over by a joint organisation which developed a plan to dispose of it in addition to the oncoming clips. So great was the demand for reclothing Europe and so efficient was the economic support by the U.S.A. under the Marshall plan, that the reserve stocks were exhausted long before the estimated time and in 1951 when a war scare occurred in U.S.A. the auction price of wool soared temporarily to great heights.

This temporary wool boom brought very high returns to the wool industries. Much of it was taken in taxation, but the remainder was sufficient to finance a great deal of the re-equipment of farms and to stimulate the improvement of pastures and the clearing of country previously regarded as economically

marginal. This investment of capital into farming was greatly stimulated by the policy of the Commonwealth in permitting the cost of many types of farm improvement to be deducted from farm gross income when determining the taxable figure. This concession also appealed to many men who, finding that their incomes were greatly enlarged, decided to buy country properties and thus qualify for the deductions. Their ultimate expectation was an enhancement of the capital value of the farm, but the immediate result of their entry into the group of people buying farms was to put up the price of farm land to levels which were uneconomic, because the returns from working them could not pay interest at current rates on their capitalisation. This has made it difficult for farmers to set up their sons on farms and has stimulated a political demand for land settlement.

These land developments were only practicable because money was available and because scientific work in the previous decade had demonstrated the importance of trace elements and had provided numerous species and varieties of pasture plants suited to various districts. Similarly many of the diseases and pests of earlier years were now avoidable or controllable. The mechanisation of fodder conservation was a development of major importance. Science was beginning to become an every-day affair on the farm; many of the younger men and nearly all the "recruits from the city" turned expectantly to scientific organisations for the solution of their problems.

The economic aspects of farming first stressed by the Development of Migration Commission from 1926-30, emphasised by the Wheat Commission (1933-5), and fostered during the war, were now recognised as part of the normal study of farming in colleges and universities. The Bureau of Agricultural Economics through its surveys of industries began to provide the economic background of the whole farming system. Farmers who had been forced into keeping accounts by the Department of Taxation had long talked of "costs of production", some of them gradually began to understand the complexities behind the calculation of any such figure. But the term was useful enough to command attention in the political field and most industries other than those of meat and wool have used it to obtain government guarantees or support in one form or another.

The gradual decline in the ratio of prices of agricultural products to the cost of labour, services, materials and the equipment required on farms has made the financial position of many farmers less secure than ten years ago. This is especially true of those who have recently entered the farming industry. One result has been the readiness of those farmers' organisations concerned with specific commodities to agree to provide money for research and for sales promotion. The current idea is that these developments may reduce the costs of production on the one hand and increase market demand on the other. The farmer alone cannot hope to solve the economic problem in a world where normal markets are saturated, but the latter might go some distance, especially where the competition is with relatively expensive synthetic products.

No palliative will solve the basic problem of markets which are fully supplied, and this has been rendered more acute by the agricultural support programmes of the U.S.A. and other countries. Britain, which was once the chief market for many of our exports, has increased her output of many products and is now a shrinking market.

The real problem of agriculture for Australia and other exporters of farm products lies in expanding the absorptive capacity of the under-supplied peoples of the world. Direct gifts, as practised by the U.S.A., offer a temporary solution, but an unsatisfactory one unless they are accompanied by the reform of the land systems and agricultural methods in those countries. If no such reforms take place the gifts will come to be regarded as normal procedures and as population pressures increase they will be demanded in amounts which Australia would find it difficult to supply agriculturally, economically and politically. The extent to which these countries can meet this problem will decide the speed at which it will be reasonable for agri-

culture to develop in Australia. Scientific work will assist in further simplifying production, raising the out-turn per man, and reducing the hazard of farming, but it cannot solve this problem of markets.

The danger of the situation for agricultural science lies in the possibility that a rural population, largely awakening to the possibilities of science and prepared to support it financially, may react unfavourably to the new idea if, the politicians being unable to solve the economic problem, markets become saturated, prices fall and hope again gives way to disillusion. If the politicians succeed then science will become more and more important as our agriculture uses a higher proportion of the poorer soil types, especially in areas of high rainfall.

CONCLUSION

This account of farming and science in Australia in recent decades may seem to suggest that agricultural progress is dominated by economic and political considerations, but that is the fact. The important feature is the change in attitude of the farmers. In many areas the majority now thinks in terms of maintaining fertility, large numbers have a glimmering idea of the soil-pasture or soil-crop complex, some understand why varieties of a pasture species are important. Or on the stock side a proportion of producers now think of foodstuffs in terms of their nutritive value and some understand the principles of genetics; but to the majority these topics are still new-fangled, and artificial insemination is a nine-days wonder. These may be gloomy reflections, but remember, young scientist, you will now be received on about 95 per cent. of farms with respect, whereas a quarter of a century ago that would not have been the case. That is an important advance and whether it is maintained depends on how you behave and on the sympathy which you show to the farmer's problems. Therefore, do not start thinking that the benefits of science which you may be bringing to the farmer's aid will provide the whole solution to his problems.

SOILS

J. K. TAYLOR

The more completely we come to know the soil resources of the land and the more research probes into their problems the greater will be national stability and prosperity. We have a vast country to deal with of which much, in terms of natural productivity, is agriculturally poor and a not inconsiderable portion agriculturally inhospitable. The farmers of the early settlements applying European experience encountered plenty of difficulties and scientists equally in modern times have found the soils full of problems different to those better known from the Northern Hemisphere. A new thinking had to evolve to deal with the Australian soils and their environment whether in regard to soil classification, fertility or land use. Where water is more precious than virgin soil fertility, the usefulness of land with assured rainfall but nutritionally of low value calls for investigation.

The Australian soil scientists of even 30 years ago were not so well briefed on their problems and perforce made use of methods and equipment tremendously less adequate than today and with a corresponding lesser background of accumulated knowledge. For it should be recognised that modern soil science has not a long history. Classical researches in the nineteenth century established a number of facts such as the colloidal properties of clay, the nitrogen fixing power of certain bacteria and then later the work of the Russian school of pedologists began to have an influence. The past 30-40 years have seen an upsurge in soil research all over the world; Australian workers have travelled in this stream with increasing vigour over the last quarter century, advancing basic knowledge, adapting and developing it to meet the fertility problems arising under the climatic conditions governing our agriculture.

The manpower available for this work has been regrettably small since the training of soil scientists has been sadly neglected by the side of the biological disciplines. Indeed the salvation has been in the formation dating back to 1929 of the C.S.I.R.O. Division of Soils as a body devoted to soil research alone with a view broad enough to cover all aspects of it. Soil research has so often, because of the course of its early study, been thought of as a matter primarily for chemists. It is only in the last 15 years we have got it into better perspective and encouraged the collaboration of other physical and biological sciences. The Universities are now fortunately tending to lift soil science to its rightful place as a basic subject in the agricultural field. This general backwardness in recognition of

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the science has held back the flow of men trained and willing to work with soils and, it may be added, often prevented, until recent years, biologists at large from appreciating the place of the soil in plant response and the usefulness of the soil scientist as a collaborator.

Soil science has developed in Australia over the last 25 years in a number of directions and we may conveniently review them under six heads—pedology, physics, microbiology, mineralogy, micropedology, chemistry and with the latter some aspects of soil fertility with which it is closely associated although this subject overlaps all the others in some degree. The tendency now is to link each aspect with the others in attacking fundamental or practical problems. Whatever may be said in the succeeding pages on achievements it should be clear that only a few of these can be even mentioned and the selection made is not necessarily the most appropriate to all soil scientists. The work which has been quoted is at least of notable merit.

PEDOLOGY AND SOIL SURVEY

Over the past 30 years the science of pedology has grown to a state of active maturity. The early work of Professor J. A. Prescott reaching expression in his classical paper on the "Soils of Australia in relation to Vegetation and Climate" in 1931, which included the first soil map of Australia, marks the beginning of a new and progressive era. His second soil map, issued in 1944, improved greatly on the original in accuracy and in number and definition of the Great Soil Groups used in its construction. These were outstanding contributions and set the pattern for the work of the later pedologists. The mantle fell next on C. G. Stephens who stated his classification system 10 years later and defined 40 soil groups adding to and expanding Prescott's previous 18 units. The publication of the first Edition of the Manual of Australian Soils by Stephens in 1953 which was succeeded by the second Edition in 1956 with an additional 5 soil groups, provided the basis commonly used for the mapping and identification of Great Soil Groups in this country. Many of these units are named for their international counterparts but a number have been set up as new groups particularly the separations used for the desert and semi arid soils. A number of Australian pedologists have contributed to this work and a new soil map is being printed this year as a current summary of available data. Mention should be made also of a new soil map of central southern Australia recently compiled by K. H. Northcote as the first of an assembly of 10 sheets covering Australia at a scale of 1:2 million. The morphological system of classification used by the majority of pedologists in Australia follows the criteria generally recognised in other countries, though healthily enough there is not complete unanimity of opinion on the definitions of at least certain terms and of some soil groups occurring here.

Some advances in pedology

The research into problems of laterite formation has been of international significance. Beginning with Prescott's theory of the pedogenic origin of laterite and an account of its occurrence and chemistry a long series of observations has been made on its formation in many parts of Australia and its relation to its siliceous counterpart, silcrete. Stephens' 1946 paper was another landmark with the discussion of the formation of soils on a dissected lateritic landscape in which bevelling by erosion had exposed layers acting as parent material for new soils. From these horizonal layers a sequence of soil formations evolved all the way from the truncated but preserved lateritic soil to podzolic soils

on underlying country rock. A third, and very recent, contribution is by M. J. Mulcahy on the denudation of the laterite formation as found in Western Australia. The stripping of the siliceous surface above the laterite, followed by the weathering of the latter and renewed stripping, provided material which, distributed by wind action, is proposed as the origin of the widespread Western Australian sandplains. It has been shown that laterite has formed on sloping and uneven surfaces and that there are age sequences in the soil formations associated with the original laterite and pediments created by its erosion.

For a long time the existence of buried soils has been observed. Sequences of surface stripping and new soil formation are common and well known and some of the best examples are in the dissected lateritic peneplains mentioned above. In the south east of South Australia wind blown sands have covered volcanic ash and also erupted material has covered impoverished sands. These are interesting from the fertility point of view. In the mallee zone stripping, weathering and recovering has gone on to produce a complex array of soils of varying calcareousness related to the dune, swale and low plain formations characterising the typical landscape.

Some more recent work by Butler in the Riverina of New South Wales has shown a considerable array of soils of aeolian and riverine origin occurring as buried layers to the extent of as many as four recognizable profile remnants beneath the surface formation. These observations lead to the conclusion that the distribution of the soils in the riverine region involves an alternating succession of conditions giving soil deposition and soil profile development on the deposited material. The former is allied to more arid periods and the latter to long periods of moist climate enabling the formation of a differentiated profile which varies in its nature on the score of calcareousness, texture, and origin whether riverine or windblown. The systematic study of these buried soils proves the periodicity of erosion and soil development and that there is a cycle comprising an unstable followed by a stable phase, the whole being called a time (or K) cycle. An application of this theory has been made in the Canberra region by v. Dijk and in the Nowra region, New South Wales, with the identification of chronologically separate ground surfaces. This has given an understanding of many complexities of the soils' behaviour such as in levels of fertility, differential responses to irrigation and drainage or liability to seepage, as well as explaining simply the pattern of soils of diverse types found in one landscape system. It is a proposition of wide application both in Australia and other countries.

A significant advance in soil study in the field has been the attack on arid soils over the past decade. The first large scale survey recorded was by Jessup in the north west of South Australia in 1951 followed by Jackson in the same region and later in Central Australia. The reconnaissance surveys of the C.S.I.R.O. Division of Land Research have given a broad comprehensive picture of the soils of Central Australia and the dry southern fringe to monsoonal North Australia. To Northcote, in 1951, is due the best pedological study of mallee soils using the survey of the Coomealla Irrigation Area in south western New South Wales as the basis for hypotheses on genesis and derivation of these formations. Churchward has followed this with studies of the dune formations in south western New South Wales applying the time cycle theory of Butler. Recent studies on arid soils in the far north west of New South Wales by Jessup are now appearing. It is too soon to sum up yet the pedological value of the research of Jessup, Jackson, Northcote and others on the genesis, classification and mapping of desert and semi arid soils but the contributions are real, both practically and academically. The recorded data of all the surveys mentioned have clarified ideas on the future of arid Australia, lifting judgment from the opinion to the factual level and bringing reality to the previously confused, often distorted, picture of more than half the Continent.

DEVELOPMENT OF SOIL SURVEYS

Pedological thinking developed along with soil surveys which themselves advanced through three stages roughly by decades. The problem which faced the soil surveyor in the early years of mapping beginning in 1927 was how to examine, classify and understand soils in a sound way. The long established practice of judging soils by vegetation and surface features gave way to study of soil profiles and classifications based on their morphology. Techniques were all important but at no stage has this subject been static and modern surveying has moved a long way ahead in the past 25 years.

In the 1930's classifications were based on a rather strict morphological approach. The mapping of soil profiles conforming to a predetermined modal type in detailed surveys led to some rigidity but on the practical side the types were allied with native vegetation or crop response. These surveys were very largely on intensively used lands and in this degree of detail, served a very useful purpose.

In the 1940's the move was more to large area surveys with or without irrigation and in this work the principle of soil associations was developed. The soil association is defined as a group of soils occurring over a landscape in a recognizable pattern in which there is one or more dominant soil types with subdominant and/or minor types associated. It represents the kind of soil areas a farmer deals with in his cultivation and cropping. As an extension of this there can be broader scale groupings of associations into combinations. Much greater attention was then paid to mapping genetic groups as Great Soil Groups to have a cover of large parts of the continent using a uniform classification. The broad reconnaissance of soils of northern Australia began in this period with the definition of a new mapping unit for land classification called the "land system".

The third stage coming in the 1950's has seen a gradual modification in technique of field study towards what may be termed pedologic mapping. Classification and mapping is now based on principles of occurrence of the soils—the landscape formations, the origin of the soil material and the genetic changes which have produced the profile. All of this is not quite new but the emphasis and the manner of approach have crystallised in a system at least equal to any devised in the world. More thought has been given to geomorphology as an aid to field study, to the formation in recent or distant past of ground surfaces on which new soil profiles developed, to cycles of erosion and deposition affecting such profiles, and to the influence of buried whole or truncated soils. Interest is rising in chronology of soils and a little dating of formations by C^{14} determinations has been done; attempts have been made to define cycles of soil formation and to correlate these over geographically separate regions. There is no slackening in the demand generally for soil surveys at all levels of intensity and if the tendency is for broader work it is because we are in a hurry to map the whole of Australian resources, particularly now the sparsely occupied country, as a basis for evaluating its future and to lay a foundation for plant and animal research.

Extent of soil surveys

In the past 25 years our knowledge of the distribution of the soils of Australia has increased enormously. The awareness of this need has been emphasized powerfully in the post war years by the land settlement of servicemen which called for many urgent surveys and in the wide surveys of Northern and Central Australia made to obtain a sound perspective of resources and potential. Unfortunately the number of pedologists has never been large and it not significantly growing. In summary the increase in areas surveyed since 1935 of which it can be said generally a moderate amount is known of the soils and soil problems is as follows—

	1935	1960
Moderate detail	2,780 sq. m.	29,340 sq. m.
Reconnaissance	—	802,000 sq. m.

It may be added that in 1935 70 per cent. of the total had been surveyed by the West-

ern Australian Department of Agriculture and that of the large increase in the reconnaissance area in 1960 70 per cent. has been due to the activity of the C.S.I.R.O. in northern Australia.

In assessing these cold statistics there are some achievements calling for mention. Between 1930-1935 the Western Australian Department of Agriculture undertook very extensive detailed surveys of parts of the southern wheat belt in connection with an examination of the salinity of cleared areas showing signs of salt accumulation and of land proposed for settlement under a Government scheme. In all a total of 5,375,000 acres were mapped closely, principally through the efforts of L. J. H. Teakle and G. H. Burvill; this has given a picture of the soils, their actual and potential salinity problems and provided a basis for understanding production in this region.

The Queensland Bureau of Investigation seeking the development of the state in the post war period undertook extensive reconnaissance surveys for land classification. The Victorian Department of Agriculture has in the same period mapped in close detail almost half a million acres on irrigation areas. The C.S.I.R.O. Division of Soils has been responsible for the survey of all irrigation areas in South Australia and New South Wales and a number in Victoria while there has been extensive detailed mapping and associated investigations over more than two million acres in the New South Wales Riverina, which paved the way for the theories on soil formation and depositional layers mentioned above. Experience has shown the foundation of so many of the advances in pedological research is laid in the mapping and field observations of surveys.

Some extensive broader type surveys have been carried out in the past 15 years. A few larger examples are the Macquarie Region New South Wales 27,000 sq. m., part of south east Queensland 26,000 sq. m., Alice Springs region 18,000 sq. m., Lower south east of South Australia 6,000 sq. m., also many smaller ones are of considerable importance such as part of Tasmania 4,000 sq. m., the south coast of New South Wales 3,000 sq. m., Perth coastal plain 1,500 sq. m. and the Portland region Victoria. Summing up, while there is not yet a connected soils cover of arable Australia, very wide areas have been surveyed at some level and data accumulated on the soils and for the remainder few large parts remain which do not include at least some mapped areas.

Land classification

Land classification, in a long history associated with explorations and land survey, had depended in the past on limited ecological and surface observations. The rise of soil surveying has placed land classification on a firmer basis. The soil surveyor has ordinarily used his soil types for grouping into land use classes and the excellent correlations developed in the Murray Valley between horticultural response and soil types vindicates this principle. It has been possible to set up the relationships of soil types to suitability for growth of citrus, stone fruits, pome fruits, vines, pasture, lucerne and some other crops. In the irrigated horticultural settlements in mallee country the definition of limiting conditions in the soils such as profile drainage, depth to calcareous layers, texture of surface soil, has become well established. In the irrigated pastoral areas attempts have been made, not without success but less well based, to divide soils into five use groups which may be selectively used for any crop from citrus to rice.

In the wider field of land classification we should note two different pieces of work based on geographic principles in northern and southern Australia. The reconnaissance surveys of the C.S.I.R.O. Division of Land Research aimed specifically at land use have covered nearly 600,000 square miles of monsoonal and arid Australia. The new mapping unit devised is the land system defined by Christian and Stewart as "an area or group of areas throughout which there is a recurring pattern of topography, soils and vegetation". The land systems may be simple, complex or

compound. The concept embodies consideration of geomorphology, geology, soils and ecology as factors shaping the land system unit. It is not a soil map but a land classification map and especially useful for sparsely occupied country.

A move along analogous lines, but in a different form, has been made by the Victorian Soil Conservation Authority in applying essentially land classification principles to agriculturally developed areas. The concept of mapping units denoting potential land use is based on environmental features particularly climate, parent material, topography, vegetation and soil, as being reasonably uniform in a given area. It also assumes a particular use of the land. In the virgin state the climax vegetation is a summation of the environment but account has to be taken of the influence of small or large changes in the other factors on developed land use whereby serious alterations in e.g. erodibility and/or hydrology may result.

SOIL PHYSICS

Water is a principal controlling factor in the great part of our arable and grazing agriculture. The strongly contrasting form of the seasonal moisture supply, the significance of which can vary with the physical state of the soil, is one of the main problems apart from erratic rainfall. The influence of strong summer desiccation on the biology, chemistry and physics of the soil is one interesting facet now receiving more attention. Essentially soil physics research in Australia is a product of the last 20 years. It has grown out of a realization that such features as water supply, evaporation, structure, erodability are vital factors in soil fertility and production.

There have been three principal trends in soil physics investigations: a. soil-water relations considering soils both in the saturated and unsaturated state over a wide moisture content; b. soil structure as affected by cultivation and crop rotation, which has moved recently towards the effects of soil tillage and mulches in regard to evaporation; c. physical changes in shrinkage and swelling and their relation to soil movement.

The first organized moves in soil physics came in the early 1940's under the pressure of airfield construction in war time and the initial work in soil mechanics dealt particularly with the characteristics of soils for the making of soil cement. There is obviously a close relationship between the soil mechanics and physics disciplines in the need to understand the basic physical properties of the soil. The interests of both these groups began to diverge later when soil physics turned principally to agricultural topics and took up studies in the water relations of soils and in the structure of surface soils.

Soil water relations

The study of soil moisture has occupied a large place in research in soil physics in Australia. Under irrigation the infiltration rates in flood and furrow systems, which had been taken up originally by Pennefather at Griffith, New South Wales, was given much more attention when the post war boom in land settlement began. A large amount of work was done in determining the irrigation characteristics of soils, from the Burdekin Valley in Queensland to the irrigation settlements on the lower Murray River in South Australia, using tests of permeability by infiltrometer techniques. Adoption of *in situ* measuring devices, tensiometers and gypsum blocks, for measuring wetting and drying processes in soils gave more precision. These prepared the way for a long series of useful field observations giving an insight to storage, use and availability of water in various soil types, particularly under irrigation conditions. This work culminated in the design of the neutron moisture meter for charting the seasonal wetting and drying sequence in soil profiles as a feature of the soil-water regime.

The most practical problems relating to soil-water in Australia involve unsaturated—rather than saturated—conditions over a wide range of alternating wetness and extreme dryness which applies to the major proportion of non-irrigated land. An elegant experiment by

Gurr, Marshall and Hutton in the early fifties dealt with the movement of water in a soil column at low moisture content near or at wilting point. In the column, which was cooled at one end and heated at the other to give a thermal gradient, there was movement in the vapour phase to the cool zone and a return liquid flow to the warm zone with the transfer of dissolved salts. Water will thus move in the liquid phase right down to the wilting point. The implications are important in considering the slow movement of salt in natural soils subject to only slight leaching from rainfall. It holds also where a saline water table exists, not necessarily close to the surface, as the movements can take place through considerable depths. There is the further conclusion that the water supplying power of the soil to plant roots may be more effective than often imagined even down to very low moisture levels.

In dealing with these calculations of permeability for unsaturated soils for which measurement is very difficult, a fundamental contribution has been the development by Marshall of new equations for relating permeability to total porosity and pore size distribution, using the assumption that the chance for one pore communicating effectively with another increases with porosity. The problem of carrying these equations to soils of finer texture containing clay is under investigation.

The most recent practical work in water movement has been the study of water balance under different treatments in a deep sandy profile by J. W. Holmes using a neutron moisture meter. This investigation, which is a forerunner of similar research, was located in the Upper South East of South Australia on a deep sandy soil typical of large areas in the region having a cover of natural heath-mallee. For comparison a stand of lucerne on the same soil type was used. The objective was to observe penetration of winter rainfall and rate of dewatering by the vegetation in the following spring and summer and further to determine whether excess water reached the groundwater table. Over a three year cycle which included one wet and one dry year it was shown that rainfall penetrated between 6 and 16 feet according to seasonal fall and that the whole addition was withdrawn by the plants. The wetting and drying curves were extraordinarily consistent. There is little known of the water balance sheets of different types of soils under different crop cover and this deficiency calls for early investigation, now that the techniques are established.

Soil structure and cultivation

The physical deterioration of surface soils under cultivation has long been recognised and the improvement under wider and varied rotations often recorded. The changes due to cultivation for periods between 1 and 20 years in a wheat fallow rotation area and in a clean cultivated orchard, were noted by Clark and Marshall in terms of the degree aggregation as compared with permanent natural pasture. This kind of mathematical comparison showing deterioration of structure and increasing degree of dispersion under long cultivation, and giving an evaluation of the observed field condition, has been applied conversely to the rate and degree of build up of structural stability in such soils under short pasture ley or lucerne or long rotations involving legume and grass. The mechanical composition of the soil and the stability of the original aggregation have a material effect on the resistance to structure loss.

A development from this line of investigation is the use of conditioning crops for improving the structural state of intractable soils. Considerable experimental work was done in the New South Wales Riverina on the growth of rice, grasses and other crops as affecting permanently the physical properties of heavy clay soils. Barley and Tisdall have recently shown that this was not so conclusive in improving structure except, and not always then, over long periods. These investigations were really probing into the means for improving the state of the surface soil of intractable clays covering very large areas in the irrigation zone of southern New South Wales. Not only was the absorption of water by the soils very low but the crusting of the surface after

flooding prevented emergence of germinating seeds of pasture plants. This problem, which was immensely important to pasture development, was solved for certain of these "unusable" soils at least, previously only cropped successfully to rice, by the work of Quirk and Davidson at Deniliquin. Treatment by irrigating with a water containing 10 milli equivalents of gypsum per litre produced an aggregated surface condition as a mulch allowing free germination and seedling emergence. The adaptation of this to practical farm usage has been achieved. The treatment is effective on soils with moderate to high amounts of exchangeable sodium on the clay complex, a feature which has been the basic cause of dispersion previously. In brief for each degree of sodium saturation there is a calculable level of electrolyte—in this case gypsum—to maintain a state of stable aggregation of the surface soil. This treatment does not make a poor soil highly productive immediately but it opens the way to satisfactory pasture development on very large areas of land commanded by irrigation and not previously usable.

Another well known condition confronting the farmer and the soil conservationist is the surface sealing of soils by impact of rain drops which leads both to increased run off and hence damaging erosion. In a red brown earth in a poor structural condition the seal was shown by McIntyre to be only 0.1 mm. thick and to be produced by washing in of fine particles dispersed by rain and compacted to a dense film by falling drops. The seal was virtually impervious to water and reduced aeration to negligible proportions, thus preventing on both counts germination and emergence of seedlings. The investigation of the causes of this and of other conditions in Australian soils giving rise to typical forms of erosion, such as tunnel erosion, have been valuable steps.

Cultivation of a pasture as we have seen leads to deterioration of soil structure. This is now seen as a reduced binding effect in soil due to loss of organic matter, previously permeating the mass of soil in the undisturbed state under a pasture. Rovira and Greacen have shown that much of the organic matter is unavailable to micro-organisms because of its presence in the soil in fine pores, 1 μ or less diameter, too small to permit access of micro-organisms. Breaking of clods and aggregates when sheared and turned by ploughing causes much inaccessible and previously unavailable organic matter to be exposed and broken down by micro-organisms. The finer the cultivation the greater the loss of organic matter. The increase in microbial activity, as measured experimentally by oxygen uptake, is related to the amount of disruption of the aggregates and cultivation to fine tilth quickly destroys aggregation developed under pasture cover.

In the last five years attention has been given to effects of tillage and shear strength of soils. The type of surface mulch created has an important influence on evaporation from a bare surface and it has been shown the least loss is under a mulch of aggregates of 2.5 mm diameter as compared with coarser ones. Indeed coarse mulches tend to lose more water by evaporation than the uncultivated surface. The establishment of such findings points the way to future design of machinery capable of producing the correct aggregation in the seed bed.

Soil shrinkage and swelling

The first study of *in situ* expansion and shrinkage of soils as affecting soil movement began in 1946 using typical red brown earth and black earth profiles at Adelaide. The black earths showed a movement on wetting as great as three inches at the surface as related to an assumed stable datum at a depth of six feet. According to the type of clay present the red brown earths varied at lesser figures while virtually no movement occurred with solonized brown soils. These movements and changes in soil volume were related to stability of building foundations but in other directions pressures set up by swelling clays have significance, e.g. in reference to development of gilgai soils.

The drying, equally with the wetting, of the expandable clays is important as affecting

the cracking and drying of the surface layers to as much as three or more feet. More recently crop growth has been studied by Waring, Fox and Teakle in relation to intake and loss of water in the black earths of the Darling Downs in Queensland. It should be emphasized again that the moisture and volume changes in soils are considered of the greatest importance in the seasonally varying conditions which affect plant growth in Australia and are a factor in soil fertility.

Attempts have been made to map soils with common engineering characteristics. Initially these were aimed at relating the pedological classification to the engineering requirements. The working hypothesis basic to these investigations—that a soil type in the pedological sense possesses reproducible engineering properties—has been accepted in practice but is subject to critical review. Within limits this appears feasible but the significance pedologically of some morphological features commonly used in classification is not always borne out in engineering usage. A map on a pedological basis was prepared in 1949 of the Melbourne metropolitan area and in 1951 of the Adelaide metropolitan area for engineering purposes. In the general field, from a knowledge of the pedology of Australian soils, it has been possible to define about 20 zones which may be characterised by the kind of engineering problems expected to arise.

In summary the advance in specific knowledge of physical problems has been steady and sound, carried forward by a small group of no more than a dozen workers. It has put out ideas plainly and in some perspective on water movement in unsaturated soils, on structural state of soils, on seasonal water regimes of profiles, on shrinkage and swelling of soil clays and very important, it has seen a development of techniques for study of soil physical problems. Achievements have been striking. The theoretical calculation of permeability of non colloidal media to water and gas flow in the unsaturated state is a notable contribution. Study of the unsaturated state, whether it be in water flow, in structural stability, in engineering character, is an aspect which, while of vital interest to Australian conditions, has not received so much attention in Europe and North America. The same applies to seasonally changing soil water profiles under alternating annual wetting and drying cycles, the latter often to the point of extreme desiccation. The importance has been recognized of evaporation from soils under mulches of varying coarseness and the effects on this of tillage depths which are shallow as contrasted with those in moist climatic conditions. Many other countries have similar problems but, as it happens, not many of these countries have advanced technology and research and in consequence Australia has done worthwhile pioneering work.

SOIL MICROBIOLOGY

There was little research in soil microbiology in Australia before 1935 and the great development has come in the last ten years with a widening of the sphere of activity and fuller entry into the field of soil fertility. The principal line of investigation has from the beginning concerned nitrogen fixation. We know, though much has been done in other countries, there are peculiarly Australian problems especially concerned with the drying out of soils, and low fertility levels. The other main avenues of research have been in availability of macro and micro nutrients in the soil, the constitution and activities of the rhizosphere flora and the study of the organic fraction of the soil.

Legume inoculation

The rhizobium story and legume nodulation had its impetus from the demand for seed inoculation for establishment of legumes—lucerne, peas, clovers—in low fertility land being developed from the virgin state. This began before World War II on the tacit assumption that appropriate rhizobia were not present which, as is now known, is not by any means always the case. To H. A. Pittman, then of the Western Australian Department of Agriculture, goes the distinction of

being the first to produce artificial cultures for seed inoculation on a commercial basis. Some years later it was taken up similarly in South Australia by C.S.I.R.O. with research into problems of nodulation and since then all States have either distributed cultures or encouraged private enterprise to meet the demand. Even before 1940 experiments were made to produce dry cultures either by drying and preserving under vacuum or by absorption onto peat—a method now well established in the eastern States.

From the early work of T. H. Strong in the mid thirties strain effectiveness appeared to vary with, and be controlled by, the host plant—whether clover, lucerne or peas—and he noted the further complication of competing strains of a "parasitic" nature. This work has gone on ever since with increasing light on the complexity of the rhizobium—legume association. From the early stages more needed to be known of effective and non-effective strains and the competition between them before much progress could be made with seed inoculation. There is a considerable heterogeneity of clover and medic strains of *Rhizobium* inhabiting one locality. The compatibility of plant and organism is no longer considered significant for *Rhizobium trifolii* although much previous work seemed to point this way. A single strain apparently can nodulate all clovers.

Documented results supporting the general use of inoculation of clover are not extensive though the evidence is strong that it is likely to be important for sound pasture establishment in some soils. Perhaps more should be done using serological techniques to define this position with antigenically labelled strains because there is no doubt of the ubiquitous occurrence of some rhizobium organisms in soils of extremely low fertility and in the complete absence of known host plants. For example *Rhizobium* for subterranean clover is naturally widespread in lateritic soils carrying heath scrub in South Australia and quite possibly this is true of other parts of the Commonwealth. To a degree in the first year of clearing the indigenous organisms can nodulate plants and progressively build up an effective population so that in the second year there is no difference in health and thriftness of the clover compared with that from initially inoculated seed.

The competition of indigenous and inoculated strains of *Rhizobium* has been the subject of extensive work in South Australia. It was shown that strains of accepted nodulating or fixing power, as determined by tests *in vitro* or in sterile sand cultures in the glasshouse, were liable to deterioration in effectiveness, and what is more significant, failed in competition with indigenous strains under non-sterile conditions. Further, success with mixed or single strains in the glasshouse was no guarantee of the result in the field plot. Study of the field plot often showed the indigenous rhizobia increased competitively under the stimulation of the legume roots. The convincing evidence in practice is that in South Australia hundreds of thousands of acres of low fertility virgin land have been sown successfully to subterranean clover without seed inoculation.

Rhizobium investigations

In a 1953 paper Harris considered that under hard natural conditions, which might be, for example, a desiccated soil under an impoverished heath cover, the organisms were located in favoured pockets from which they might spread under stimulus. He referred to their power of "incursiveness" in being able to multiply and invade the rhizosphere zone from such pockets. The incursive quality might be greater in indigenous rhizobia than in the cultured inoculated strain so that under competitive conditions the latter became less effective and died out. Vincent and Harris both showed a variability in powers of strains of rhizobia to invade roots and that a strain may lose this capacity. The argument on inoculation is that a strain of good invasive power inoculated on the seed is in the best position to nodulate the roots and compete with rapidly multiplying indigenous rhizobia which might produce useless nodules of low nitrogen fixing capacity.

There is little if any effective cross inoculation with the native legume flora from which something more than 100 isolates have been made. Recently, for the first time, it has been reported some cross infectivity is possible with lupins in Western Australia. However, while from these sources a widespread rhizobial flora has been indicated, it is fairly clear that it is not a significant factor in nodulation of pasture legumes. It has not yet been established what is the significance of the nodules in the nitrogen economy of the native plants and soils.

Recent studies of the taxonomy of *Rhizobium* have shown it to be very different in its constitution to the earlier concepts, indeed that it may be a mixture of types and not belong to one genus at all. The concentration of investigation has been on plant—bacterial relationship but a better understanding of such observations as the occurrence of multicellular rods, endospores, rough and smooth colonies and ones of variable gumminess, is needed to clarify the fundamental bacteriology of the genus. Evidence has accumulated on this subject.

Elements necessary for normal growth and functioning for nodulation of *Rhizobium* have been shown for Australian soils as phosphorus, calcium and magnesium. As far as has been established the organism obtains all trace elements it requires even from low fertility soils. There is a clear relationship to acidity of the soil. The addition of lime in small amounts with the inoculated clover seed, shown to be effective in deep acid sands in Victoria by Pittman and in South Australia, has allowed local proliferation of rhizobia and invasion of the root system. The development of low fertility acid sands has long presented a problem to agronomists in southern Australia and this appears the solution to clover establishment.

Rhizosphere studies

Some very interesting results have come from the work of Rovira and others at Adelaide on the rhizosphere population and its influence on the plant and on soil flora. Roots are known to produce an exudate according to the type of plant and environmental conditions and this has a marked effect on the micro-organisms in the immediate vicinity. This rhizosphere zone about 1 mm thick develops a large population whose constitution varies with the plant. *Rhizobium* spp. are favoured by legumes but may be virtually absent from non-legume roots. On the other hand phosphate solubilizing organisms formed one third or more of the flora in the rhizosphere of clover or grasses, being in both cases much higher than in the whole soil. The stimulating effect comes apparently from vitamins in the root exudate encouraging microbial growth. Very recently it has been shown that the rhizosphere flora have an effect on the rate of elongation of roots of the seedling plant and on the production of root hairs. This line of research is young —it may well lead to some very useful findings especially in conjunction with studies of *Rhizobium* and organisms solubilizing insoluble phosphatic materials.

Phosphorus and nitrogen are the principal limiting nutrients for micro-organisms as the deficiency shows experimentally in a marked reduction of oxygen uptake and CO_2 production. In consequence both elements were studied more closely by respirometry, using apatite and a number of phosphatic fertilizers and minerals of varying high to very low solubility. It was practicable to show that the materials could be graded into groups of readily available, fairly available, and poorly available, sources and this degree of availability was paralleled for plants and micro-organisms. This technique is therefore highly useful in tests of the phosphorus supplying power of unknown phosphatic materials. Continuation of this bioassay work into the attack of soil organisms on phosphatic minerals commonly occurring in the soil clay fraction proved them unavailable in appreciable amounts. When it is understood a large part of the phosphate naturally present in soils is in the least available form its contribution to the problem of infertility is obvious.

SOIL CHEMISTRY AND FERTILITY

The study of the inorganic chemistry of soil has a long history and indeed soil research and agricultural chemistry were long considered synonymous. There was virtually no other soil research done in Australia until 30 years ago when the first moves into pedology and into microbiology occurred. But the decade of the '30s was an active and very notable one in the study of trace elements in soils and of field deficiencies for plant growth. Manganese, picked up in 1928, was the first of these and subsequent years showed the extent of this deficiency in South Australian soils. The chemistry of manganese and the forms in which it occurs in the soil have been intensively studied since. By 1935 copper and zinc were also shown as limiting in South Australia through unavailability in the soil; attention was focused first on copper and later in 1938 on zinc. Boron deficiency showed up in 1936. In 1940 molybdenum was suspected to be an essential micronutrient for clovers and this was confirmed the following year. In all these investigations the soil chemist entered as a working partner with the agronomist. It was a chemist who first found manganese deficiency, and a spectrographer who first suggested molybdenum.

Intensive examinations have continued of the trace element status of Australian soils by chemical, and spectrographic methods. The difficulty is not in determining the gross amount but the availability. In this the pedologist, by soil classification and analogy of observed field deficiencies, and the microbiologist, by laboratory tests, have helped in assessment. A long continued series of spectrographic analyses have been made of soils representing Great Soil Groups in South Australia, Tasmania, Queensland and Central Australia. These have been extended to a wide range of soils to see the usefulness of spectrographic determination of trace elements in fertility surveys. The notable technical skill achieved by Australian spectrographers in soil studies and the application of statistical methods to interpretation of results—a field largely pioneered by them—has placed this work on a high level. Geochemical investigations which have scarcely begun as yet may profitably take advantage of it.

As Australian soils are almost universally deficient in phosphorus it is natural considerable research has gone into the study of this element. In 1958 Wild summarised the known distribution of phosphorus showing the extremely low values for total P_2O_5 as compared with other countries in the great majority of soils, irrespective of their classification, in southern, central and northern Australia. This is ascribed to the parent material, to the influence of soil age and the leaching which the soils have undergone in past time. Much work on the availability of applied phosphatic fertilizers, either in the year of supply and as a residual effect subsequently, has shown the capacity of some soils, such as the red brown earths and podzolic soils, both to respond immediately and to have the capacity to accumulate an available residue. The best example of this is in the examination by C. S. Piper and others of a red brown earth at Adelaide where a total application of 23 cwt superphosphate built up a reserve sufficient for production of normal wheat crops for five years without response to additional fertilizer. The capacity of soils to build up a source of residual phosphates available to crop and pasture plants is related to their mineralogy. This was demonstrated by Tyson in experiments with a lateritic podzolic soil on Kangaroo Island with a dominance of kaolin and gibbsite in the clay fraction where fixation of the phosphate removes the soluble supply. It has been established that the availability of phosphate is governed by four principal factors—the fixation capacity of the clay, pH, exchangeable cations and soil organic matter.

As with the phosphate story, and there is much more to this than the little given here, so with all phases of soil chemistry, knowledge is accumulating and presenting a better view of fertility problems. For example factual evidence on the building up of soil fertility by long term growth of pastures including clovers has been nicely demonstrated by Donald and Williams in a podzolic soil in New South Wales with the addition of 13

cwt of superphosphate. The phosphorus, sulphur and nitrogen content of the soils doubled in 25 years whereas initially all were seriously deficient in these elements. A new ratio between carbon, nitrogen, sulphur and organic phosphorus was defined and used as a measure of chemical changes in the soil, and this provides also a useful yardstick for similar investigations. The converse case of nutrient decline on continued cropping of a fertile soil has been examined for the black earths of New South Wales by Hallsworth and his associates. The seasonal variations in nitrogen and soil moisture in the black earths of the Darling Downs in Queensland under wheat cropping have been followed in some detail by Waring, and Martin and Cox.

While much of the chemical research has led out directly onto questions of soil fertility there have been some basic investigations such as those by Raupach on the nature of soil pH; Leeper and Beckwith, on the chemistry of soil manganese; Martin and Reeve on illuviation mechanisms for movement of organic matter in a podzol; and Stace on the degree of distinction between terra rossa and rendzina soils. These and other fundamental studies have implications beyond the Australian scene.

An outstanding contribution to soil research has been the working out of methods for analysis which are continually under review. Such important techniques as those devised for fractionation of soil phosphorus and soil sulphur in relation to availability, for available potassium, for exchangeable cations, for spectrographic analysis, to mention only a few, have given soil analysis much more meaning. Publication of C. S. Piper's book on Soil and Plant Analysis in 1942 was the first comprehensive step but a long series of improved individual methods has followed in the literature. Chemists are much better armed for routine and research analysis. This is particularly valuable as moves are afoot to assess the fertility levels of soils classified during soil surveys and where these involve virgin lands the potential problems may be more readily foreseeable.

Soil fertility has been a great problem everywhere in Australia especially as the pressure on agricultural land has become greater to produce more per acre economically and as the land hunger of recent years has forced on the development of large areas of new land of marginal value. Soil research from the chemical angle has endeavoured with considerable success to meet the demand for new knowledge. The part played by microbiology and physics is of increasing value in association with the chemical approach in interpreting the agronomic result.

CLAY MINERALOGY

Research in the clay mineralogy of soils began in 1946 within the C.S.I.R.O. Division of Soils and almost all the subsequent work, apart from that on ceramic clays, has been developed from it. The future possibilities are bright, particularly in the association of these researches with those of micropedology and chemistry. As with all new sciences preliminary work on techniques was necessary and the principal advances have come in the last seven years. These have been notable both on the fundamental and applied sides but a much clearer picture is emerging of the nature of clays in Australian soils and their influence on the chemical and physical properties. The development and use of techniques in the study of soil mineralogy involving x-ray diffraction, spectrography and differential thermal analysis is of considerable significance in the balanced approach to soil research.

Parallel to the earlier work on the chemistry of some of the Great Soil Groups a study was made of the clay mineral constitution of three of these—the solonized brown (mallee) soils, the red brown earths, and the terra rossa—rendzina group. One characteristic common to all was the presence of a considerable proportion of illite which is more prominent than in many foreign soils. In the solonized brown soils illite formed as much as 75 per cent. of the total clay minerals present. The red brown earths showed a close relationship of parent material to content of illite. Soils associated with the alluvial, sedi-

mentary or loessial deposits of the red brown earth zone had clay fractions made up very largely of mixtures of illite and kaolin; those formed from acid and basic igneous parent material were dominantly kaolin. The terra rossa and rendzina soils were high in illite also. Another feature of the Australian illites of importance is their lower potassium but higher exchangeable cation content compared with illites from Europe and North America. This may have significance in potential potassium deficiencies.

A long series of examinations of the phosphatic minerals in soils has revealed the presence in notable amounts of gorceixite and florencite in a wide array of soils independent of their parent materials. These minerals in which the phosphorus is highly unavailable were often thought of as rarities but this is not so and in some cases gorceixite has accounted for as much as 70 per cent. of total phosphorus in the clay. As an additional point nearly all the copper in some soils has been found combined in the unavailable phosphatic minerals. These are interesting data for the soil chemist and bear also on fertility.

Some striking advances have been made in the determination of trace elements by x-ray fluorescent spectroscopy. The method so far applies to all elements with an atomic number above 40 but it may be extended in the future to cover, with the aid of a vacuum spectrograph, the lower range also. This would enable the picking up of such important elements as sodium, magnesium, aluminium, silicon, phosphorus, potassium and calcium. This is a highly useful analytical approach to soil chemistry particularly if the accuracy of estimation to within 1 per cent. over a wide range of cencentrations can be maintained as has been found with zinc, iron and manganese at the present time.

MICROPEDOLOGY

It is still early to say much about this interesting field of research which has been followed in Australia for only a few years. Sporadic mineralogical analyses of the sand fraction of soils had been carried out in the past but it became obvious that the soil should be considered and examined as an undisturbed body. Since Kubiena published his book on Micropedology in 1938 there has been a slow development of research interest in the microscopic study of naturally occurring soil. In the past five years Brewer and co-workers at Canberra have gone into the techniques and fundamental principles and produced data of considerable value particularly to pedologists and physicists.

Soil materials are highly heterogeneous. Field examination has shown the need for greater detail in study and description of horizonal features to aid with morphology. The microscopic approach has enabled such a closer examination. The methods of the sedimentary petrologist have been adapted and a technique of preparing thin sections of the natural soil developed. Carefully selected material from the field sample is impregnated with a plastic, and subsequently the hardened mass is ground down to a thin section, much as petrologists use for rock examination. From these thin sections microscopic study reveals characteristic features of the fabric and structure of the undisturbed soil, including the types and degree of weathering of the minerals present, and the porosity. The soil can be studied as to its mineral skeleton which is virtually stable and the clay, sesquioxides and organic matter, called collectively the plasma, which is subject to change. The plasma is the seat of activity for reactions in the soil and governs most of its characteristics and properties.

Skills in preparation and experience in interpretation have been acquired to a high degree. The first stages of drawing up descriptive specifications are now appearing in the definition of terms and concepts which combine those of the pedologist with the sedimentary petrologist to give precision to loosely used terms such as structure and texture. There is a long way to go still before such are accepted and used.

It is now being realised that micropedology can be invaluable in assisting with interpreta-

tion of other analytical data as well as helping the pedologist in his field assessments. The methods perforce used in preparation of a specimen for chemical analysis involving grinding and sieving may lead to some anomalies. For example it is not uncommon to find concentrations of manganese on the walls of some voids but the soil mass as a whole may be deficient. The problem then is to determine whether the mode of occurrence has significance in soil character. The development of clay skins, or cutans, and the segregation of sesquioxides are very important in understanding soil properties. The clay mineralogist is clearly interested in these and also such things as how the plasma is distributed through the soil material, the identification in it of the amount of layer lattice minerals, sesquioxides, calcite, etc. The soil physicist is particularly concerned with the voids—the shape and arrangement of the macro pores which affect permeability—and the clay skins on the soil aggregates which affect swelling and the rate of break down of soil clods on wetting. An obvious physical characteristic that can be seen is the density of packing of sand or mineral grains in horizons which act as a hard pan without cementation.

The study of soil genesis is a field in which micropedology provides valuable clues. An excellent example is Brewer's 1955 paper on the evolution of a yellow podzolic soil on granodiorite. Another is the same author's identification by petrographic techniques of the distinction between two soil series occurring together in the field and with the same parent material but with a difference in development of the profile due in one case to movement of clay and in the other to *in situ* formation of clay in the B horizon.

Micropedology has considerable significance in most branches of soil science whether it be in classification, soil genesis, physical properties, or interpretation of chemical data. It assists the assessment of the soil as a growing medium for plants as a root environment, involving permeability and accessibility of nutrients dependent on structure and fabric.

CONCLUSION

Briefly we may look ahead at where soil research may lead in the next few years. It is becoming more recognized that the soil-plant-animal-soil cycle has to be attacked from all sides, differently to the past practice of each group dealing with its own problems. It is not a matter of intrusion but of intelligent collaboration between fields of interest. This relates to fundamental as well as applied problems. The soil is basic to both plant growth and its quality as food for animals and both plants and animals affect the character of the soil. Nothing is static about a soil however timeless its characteristics may appear to our observation. The plant and animal merely quicken changes which to the skilled pedologist, physicist, chemist and microbiologist may be anticipated and measurable.

We may foresee a continued drive to assess and map soil resources all over Australia at first in the broader scale, later, and as profitable, more intensively. The techniques, classifications and interpretations are well established for progress in survey. With the surveys will go a better understanding of the pedology of the soils, of their origin and genesis and principles of occurrence.

In the field of soil chemistry we may anticipate a continuance of the work on phosphorus, potassium, nitrogen and the trace elements. The glamour of agronomic response to micronutrients is passing but we know so little of the forms and chemistry of them in the soils of different types. Deficiencies are all around us although adequate gross amounts exist unavailable to the plants. This and parallel gaps in our knowledge of the chemistry of phosphorus and of organic matter are to be filled. There will probably be a greater drive for measures of availability of elements and an assessment of soil fertility. The mapping of this along with soil surveys is beginning and must develop especially along with greater use of tropical areas and opening of new country in southern Australia. One aspect that is important is the foreseeing in advance of fertility problems which may arise in the course of more intensive management of low fertility land with incipient deficiencies.

The tropical north and the great area of potential development in subtropical Queensland will call for increasing attention. Although there is probably much less than imagined in the often quoted theory that tropical soils are "different" it is true that they have not had the close investigation that southern areas have had. The degree of ignorance is relative; the same lines of research and techniques are applicable. There is however a clear need to push this work forward in all aspects of soil science and it is not only a chemist's problem. Here too we may expect to find in an acute form the problem of desiccation and its effect on the biology, chemistry and physics of the soil.

Microbiology will enter more widely into the complete research pattern in many fields besides nitrogen fixation to which major attention has been given so far. We shall learn more of organic matter changes and humus in the soil, more of the breakdown of hydrocarbons, more of the activity of microorganisms and their relation to plant root systems. The microbiologist will be more concerned with applied research in soil fertility.

In soil physics we may expect to see a great development with the realisation of its importance in soil fertility in the broad sense. Annual water balance in the soil profile in different soils under different climatic regimes and the estimation of evapotranspiration and drainage losses will be valuable. Tillage systems and soil structure and the examination of evaporation from soil surfaces, which have recently begun, may continue with profit.

Much may be hoped for from research in mineralogy and micropedology in association with other aspects of soils investigation. These two approaches have a great chance of clearing up ideas on the nature of the clay fraction and its function in the soil. They have a close relation to geochemical studies and provide data for the physicist interested in soil structure and the pedologist in pedogenesis of profiles.

These are some of the lines of progress we may look forward to in the next few years as practical research. It is to be hoped a balance in work between all sides of soil science can be maintained and that there will be collaboration between them and with other branches of agricultural science. The fundamental study should bulk largely although the applied side must, in this developing country, receive greater attention. The harvest is potentially great, the labourers unfortunately few.

AGRICULTURAL SCIENCE
IN AUSTRALIA 1935-1960

CROP AND PASTURE PRODUCTION

C. M. DONALD

The great changes in Australian plant production during the past quarter century have been due to many factors, but above all to better plant nutrition. In some instances only fertilisers have been involved, but often the nitrogen of legume nodules has been inseparable from the use of fertilisers in giving better plant growth. These are simple things — fertilisers and legumes — yet their effective exploitation has involved all sorts of workers — those in ecology, agronomy, plant selection, bacteriology, plant nutrition and physiology. In turn the better nutrition of our crops and pastures has had many major consequences such as the adoption of new land use patterns, reduced dependence on bare fallows, increased fodder conservation, a changing incidence of pests and diseases and for many regions, a greatly stabilised agriculture.

Though a little tedious, it is useful first to examine the overall figures for the volume of our crop and pasture production since the mid-thirties. We show no increase in the acreage of crops during this quarter century, a surprising situation in a developing country dependent on agricultural exports. In 1955-59 wheat is down by 5.6 million acres from its 15.2 million acres of 1931-35, though the area of coarse grains has partly compensated—barley has increased from 0.4 to 2.0 million acres, oats from 1.3 to 2.9 million acres and grain sorghum from a few thousand acres to 0.21 million acres. Among the more intensive crops, some of the notable changes are an increase in sugar cane from 0.32 to 0.47 million acres, a decrease in potatoes from 0.14 to 0.10 million acres and a more or less unchanged area of 0.4 million acres of orchards and vineyards. All in all, there is nothing in these figures to suggest progress.

However if we look at yields per acre the picture is much more reassuring. Wheat has moved spectacularly from 12 bushels per acre in 1931-35 to 17 bushels in 1955-59 and barley is up from 18 to 23 bushels. The principal factor in these increased cereal yields has been the improved chemical and physical fertility following the introduction of leguminous leys into cereal rotations. Potatoes have moved from 2½ to 4½ tons per acre, sugar cane from 2.6 to 3.2 tons raw sugar, and apples from 95 to over 150 bushels. In these crops the heavier use of fertilisers and better plant protection have been the main improvements. All these examples indicate satisfying gains in the efficiency of our crop production.

We can now turn to the second great category of plant products — our pastures. Here no direct criteria of plant production are available and in any case the value of the improve-

ment of our pastures must be rated by animal output. While there are many studies which show dramatic increases in stock numbers on individual holdings there are few surveys of broader nature. The most useful for our purpose is that of New South Wales by Gruen, who showed that in shires with increasing stock numbers between 1927-31 and 1947-51 "on an average an increase of ten acres under sown grasses was associated with an increase of eleven sheep". It is not unreasonable to attempt to apply this criterion across Australia. The only relevant figure in the Commonwealth statistical data is for the area topdressed each year with fertiliser, and this rose from 4 million acres in 1935 to 24 million acres in 1959. Thus we added 20 million acres to our annual fertiliser programme, and if we assume that on the average, fertiliser is applied two years in three, then there has been an increase of 30 million acres in our sown, topdressed pastures. On Gruen's figures these pastures will have added 33 million sheep equivalents.

Our livestock population has actually increased by 60 million sheep equivalents (one beast = eight sheep), so my estimate suggests that sown pastures have contributed 55 per cent. of the increase in stock numbers since the mid-thirties.

In summary, the picture of plant production for the quarter century is of a decreased area of cereals but with yields up by about 25 to 40 per cent., of little notable change in other crop acreages but again with substantially increased yields, and of a great advance in pasture production and thus of stock numbers. Because of the contribution by pastures both to cereal yields and stock numbers this period can properly be called "the pasture era".

THE PASTURE ERA

Species and fertilisers

The Australian viewpoint on pastures in 1935 had its origins in much earlier events. We can trace back to Howard's recognition of the value of subterranean clover in 1889, a recognition that we could develop new pasture species, not already in use overseas. The other starting point was the use of superphosphate on Australian soils by Lowrie at Roseworthy College. These were the beginnings of the Australian outlook on species and fertilisers for sown pastures.

By the early thirties several 'new' plants had been successfully developed for pastures in Australia. Subterranean clover, Wimmera ryegrass and Phalaris, accidental or deliberate introductions from the Mediterranean, were in limited commercial use and it was becoming realised that the Mediterranean flora offered great prospects as a source of useful material for southern Australia. The flow of material from many parts of the world into tropical and subtropical Australia included several useful grasses, though the widely adapted legume for these regions seemed ever to be more elusive. Plant introduction, previously conducted in unocordinated fashion by a multiplicity of agencies, was now greatly accelerated through the establishment of a Commonwealth introduction service.

In southern Australia it was the very success of subterranean clover over great areas that drew attention to a group of new problems; it emphasised by contrast the failure of this species on a variety of soils despite heavy superphosphate and inoculation. This stimulated two lines of attack — were there pasture legumes which would do better than subterranean clover on these sites? Or alternatively could fertilisers be applied to make the subterranean clover grow? By this time—but not earlier — agronomists were coming to realise that the emphasis in pasture development on very poor soils had to be almost wholly on the legume because this was the only cheap source of nitrogen. In addition to subterranean clover, white clover was already in use in favoured areas and the Palestine strain of strawberry clover (*T. fragiferum*) and barrel medic (*M. tribuloides*) were added to the list in the late thirties. These few legumes, subterranean clover, white clover, strawberry clover, barrel medic and lucerne have provided the basis of pasture development in southern Australia. From the late twenties onwards additional varieties of subterranean

clover, all found in this country as naturally occurring strains, have been commercialised and these have extended the regions in which subterranean clover can be grown by many tens of thousands of square miles. But it is surprising that since the late thirties nothing other than a couple of new varieties of subterranean clover have been added to this sown legume flora of southern Australia. We may attribute this to several factors, to the success of the goodly array of sub-clover varieties, to the great range of environments covered by the few species already in use (this includes for example the use of strawberry clover on water-logged soils, the use of subterranean clover on extremely poor podsols and the use of barrel medic on alkaline marginal cereal soils), and to the heavy emphasis on nutritional problems over much of the past quarter century at the expense of species studies and plant improvement. But the legume needs of southern Australia are still unsatisfied, the greatest deficiency being that of wholly suitable ley legumes for many cereal areas.

The alternate attack on legume failure was through the use of nutrients and this proved remarkably successful. The calcareous sand at Robe in South Australia was such a soil — subterranean clover, white clover, lucerne, barrel medic and many other species had failed completely. Here the first trace element response by pastures was recorded, a response to copper. It was not the first trace element response in plant production in Australia — that had been the response by oats in 1928 — but it opened a new phase, the use of trace elements to enable growth of pasture legumes and thereby the building of soil fertility.

Throughout the past quarter century, the use of phosphorus and trace elements on pasture legumes has perhaps been the most dramatic of all the events affecting plant production in this country. Copper response by lucerne and black medic in 1938 was followed by zinc response of subterranean clover in 1948 and molybdenum response in 1942. These elements have done much more than remedy diseased conditions of pasture plants. By enabling the growth of legumes they have permitted the development of previously worthless lands on a scale and to a degree not dissimilar from the reclamation schemes of peat or sea floor in Europe. Phosphorus, sulphur, lime, and the trace elements, have been economically profitable fertilisers for these poor lands, but the acute nitrogen deficiency could not have been met with profit by the use of fertiliser. Rhizobial fixation of nitrogen has been a key part of the economics of this land development.

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These pastures, established by "scratching" clover into native pasture or by seeding on newly cleared areas, characteristically show extreme clover dominance in the second or third year, and it may be several years before nitrogen has been raised to a level permitting grass development. This now seems a simple and obvious sequence of events but it was by no means fully understood in the mid-thirties. When clover was excessive, the advice was to reduce the superphosphate dressing — the exact reverse of the advice now given. Work on the failure of Wimmera ryegrass extended even into the fifties, when again the key proved to be a satisfactory clover-induced nitrogen status. We now appreciate that a clover dominant sward is an essential phase of fertility building and that the greater the clover development, the more rapidly will the sward evolve to a grass-clover mixture.

Major nutrients on pastures

In southern Australia the peak of the great surge of work on trace element deficiencies of pastures is passing. Though areas remain with undefined deficiencies, though more information is needed on rates and frequencies of application, the main pattern has emerged. Trace element deficiencies, once defined, can

usually be remedied at low cost and for long periods. It was in this circumstance that attention turned again in the fifties to the major elements, to nitrogen, phosphorus, potassium and sulphur.

Our understanding of phosphorus and pasture growth is still quite incomplete. The earlier approach to the use of this fertiliser was in terms of "the optimum annual dressing". But we now know that on many soils the phosphorus available for plant growth is directly proportional to the cumulative amount applied during preceding years — probably at least up to 20 years on some soils. This leads to a fertiliser programme based on the concept of a "soil phosphorus bank" and on the curtailment of dressings when the bank is sufficient to supply all plant needs. Here is a very important milepost—a point at which we may say "These soils need only a small maintenance dressing — phosphate resources can be diverted to more needy soils". Because our phosphorus resources in the Pacific Islands are so meagre it is especially important that we should distribute our supplies to best advantage. As yet the area of soils on which only maintenance dressings are needed is small but it will become substantial in the next ten or twenty years.

This transition to maintenance dressings for reasons both of economy and conservation of supplies, is in marked contrast to the position in the United Kingdom, where expert opinion suggests that 90 per cent. of the phosphorus at present being applied gives no response. It is there felt that the building of soil phosphorus resources above immediate response levels is sufficient purpose in itself, though it may be questioned whether farmers would subscribe to this viewpoint if it were explicitly stated to them.

Unfortunately this build-up of available phosphorus does not occur on all soils, and here sharp problems remain. On some soils phosphorus is fixed in such forms that production rapidly declines if dressings are discontinued or decreased, even after a history of heavy application. Evidence from Western Australia shows that on yet other soils, particularly of low organic matter and clay content, phosphorus is leached downwards and probably away by drainage. In each of these circumstances work on the form of the fertiliser and on the role of incremental organic matter in phosphorus retention is of considerable urgency. Somewhat similar queries apply to the use of sulphur on pastures, with high residual effects on some soils, poor on others. Potassium, an expensive imported nutrient, also presents problems as the rising phosphorus and nitrogen status of many soils strains the meagre potassium resources.

Pasture problems of the north

Pasture development in the tropical and sub-tropical regions of Australia has made little progress compared with that south of latitude 28°S, but the whole pace of pasture studies in northern regions has accelerated in the past decade, and the establishment of the C.S.I.R.O. Division of Tropical Pastures has given new definition to the targets ahead. Here is a region in which the whole species pattern must be resolved *ab initio*. At present pasture development is hindered by the unavailability of widely adapted legumes. Townsville lucerne (*Stylosanthes sundaica*) is in limited commercial use on poor coastal soils, *Centrosema pubescens* in the wet tropics and lucerne in southerly parts of Queensland. In addition a large group of genera — *Vigna, Desmodium, Phaseolus, Indigophera, Lotononis, Glycine* and others — offers material of considerable promise, but there is at present no legume in extensive use. Workers in Queensland emphasise that earlier efforts to develop pasture legumes were hampered by the lack of understanding of the climatic conditions and of the poverty of many of the soils and by the failure to introduce effective strains of *Rhizobium*. There are now prospects that successful pasture legumes can be developed for these tropical and sub-tropical climates and a considerable programme on these species is in progress. The need for parallel research on the use of fertiliser nitrogen on pure stands of various introduced grasses is equally pressing. The search for widely adapted tropical

legumes has been going on, albeit rather spottily, for 30 years and it may be that a good many years have yet to elapse before the problems of nitrogen deficiency in these tropical areas can be solved through legumes. On the other hand the grasses are already available. Though nitrogen is at present expensive in Australia the price trends in other parts of the world suggest that a situation could arise in which heavy nitrogen dressings on pure grass pastures would pay handsomely in increased beef production. *Sorghum almum,* a highly productive South American grass, has been estimated to have a potential distribution of some 50 million acres in Queensland, but neither its full yield nor its full geographic limits can be realised unless it has either a successful associate legume or applied nitrogen. These stand side by side in importance as fields of research. Experience in many other countries has shown that, where no legume can be successfully used, combined nitrogen has provided an alternate route to high production.

Work on mineral deficiencies in these northerly areas is presenting a very diverse pattern, from black earths of moderate fertility to the grossly deficient soils of the Wallum. This latter coastal region north of Brisbane shows a greater number of deficiencies (N, P, K, Ca, Cu, Zn, Mo and B) than has been recorded elsewhere in Australia. Yet it has been said that this region "will become the food-bowl of Brisbane", and indeed the research already completed shows that development is now conditioned more by economic factors than by the lack of knowledge of how the job can be done. On the more fertile soils such as those of the Brigalow scrubs there are prospects of some pasture improvement without initial recourse to fertilisers by replacing low producing native species with productive introduced grasses, and by accepting submaximal yields. But eventually legumes or combined nitrogen must be provided.

Rhizobium studies

A most successful phase of our pasture research has been our contribution to *Rhizobium* studies, both as they relate to Australian problems and as they contribute to general knowledge of nitrogen fixation in legumes. Work in the thirties established that even among the species of *Trifolium, Rhizobium* strains were of varying efficiency and that distinct cultures should be developed for use on the several clover species. Another interesting step at that time was the abandonment of polishing subterranean clover seed. It had become a practice to add a little linseed oil to give the seed a most beautiful black lustre. But this process removed the *Rhizobium*-infected dust from the seed and partially sterilised the surface. Experience with unpolished subterranean clover has shown that even on new lands, benefit from inoculation is slight or uncertain, and though inoculum is available in all states most subterranean clover is sown without it. This contrasts from peas, lucerne, lupins and various other legumes in particular situations. In some districts, such as the north coast of New South Wales, inoculation is a key part of the programme.

Very useful information has come from surveys of the Rhizobial flora of the soils of various parts of N.S.W. and S.A.; these have shown populations of greatly different composition in different regions. In the Lismore district for example the flora includes large numbers of bacteria effective on red and white clovers but almost always parasitic on subterranean clover and crimson clover. In other localities the composition is quite different. This information has permitted firm decisions on the seed inoculation programme to be followed in each district.

A most significant development affecting legume establishment, nodulation and nitrogen fixation in the field has been the increased understanding of the environmental conditions governing these processes, in particular the influence of lime in the vicinity of the germinating seed. Lime has never been used in great quantity in this country because it is expensive to transport long distances and because responses were rarely profitable. In fact in the minds of many agronomists, lime lay with the muck-and-magic group of fertilisers — a part of European tradition with no place on the

Australian scene. This scepticism has proved valuable — it has meant that lime has come into use only where its usefulness for a particular purpose has been thoroughly established. At present the principal use of lime is as a light dressing drilled with the seed, a technique of the greatest importance in successful pasture establishment on many soils in all southern states. The whole phenomenon of the separate influences of calcium status and of pH changes is being dissected in terms of the growth of *Rhizobium* in the soil, the growth of the host plant, nodule formation and nitrogen fixation. Perhaps the most surprising findings have been the negligible requirements by *Rhizobium* for calcium, confirmed both for subterranean clover and for tropical legumes, and the independence of responses shown by host and *Rhizobium* to pH changes.

The analysis of these complex and interacting factors is enabling a re-examination of field nodulation problems and a thoroughly rational approach to the use of lime or other compounds as agencies for the provision of calcium to the host or for the raising of pH.

A particularly interesting viewpoint developed from work on legumes in tropical Australia is that the important temperate group of legumes, the Trifoleae and Viceae, represent a relatively recent and highly adapted offshoot from the main body of legumes, which is essentially a tropical family. Most of the Rhizobial studies of the world have been done on temperate genera, on *Medicago, Trifolium,* and *Vicia* and it may well be that the extrapolation of concepts from these few genera to the tropical Leguminosae has led to many wrong assumptions regarding nodulation and nitrogen fixation in these tropical regions.

No account of *Rhizobium* studies in Australia would be complete without reference to the very significant work done on molybdenum. Following the first records in the world of field deficiencies of this nutrient, it was established that so far as clover development is concerned, the molybdenum level is usually sufficient to enable nitrate reduction in the host plant but insufficient to permit nitrogen fixation within the nodule. This understanding of the roles of the applied molybdenum has in turn permitted an appreciation of the inter-relationship of the use of lime (as influencing Mo availability), molybdenum status, nitrogen supply (fertiliser or atmospheric), and plant growth. The work provides a very beautiful example of the reduction of chaos to order under the influence of good research and a penetrating mind. Following the recent discovery in the United States that cobalt also is essential for nitrogen fixation by *Rhizobium,* we await the results of Australian tests for field deficiencies of this element — it may open further prospects for the use of legumes.

Fertility lift

When pastures were first sown in Australia, the purpose was straight-forward and uncomplicated — it was to provide better grazing for man's animals. This philosophy continued into the early thirties, but as subterranean clover became more widely used, it was realised that not only was more and better feed being provided but that tremendous changes were occurring in the fertility of the soil. The nitrogen increment, amounting to some 40 lb or more per acre each year under farm conditions, was raising fertility to quite new levels— a rise for example from 0.05 per cent. nitrogen to 0.20 per cent. in a couple of decades. Grass invasion of clovery swards was recognised as the characteristic expression of rising nitrogen status.

But though nitrogen is the vital contribution by the legume, it may be that we should regard carbon as the central element in this fertility lift — or, in respect to our forebears, say that the quintessence of all this change is humus. Carbon is the dominant element, with a ratio of carbon, nitrogen, sulphur and organic phosphorus in the organic matter added by clover of the order of 160: 10: 1.5: 0.7 though with variation in all components. Superphosphate has provided phosphorus and sulphur; legume and rhizobium have provided and mutually shared the carbon and nitrogen.

If for any soil the ratio of these elements is approximately constant both in virgin and

incremental organic matter, as Australian studies suggest may be the case, then together they must rise and together fall. And if this is so, then the increment of organic matter must depend on a sort of law of the minimum, the increment governed by the rate of which the least of these elements is entering the system. All sorts of implications spring from this thesis. For example rock phosphate or triple super would be far less effective than superphosphate in raising organic matter status, and the minimum factor would presumably be the sulphur of the rainfall. If phosphorus is leached or fixed by inorganic processes, this element may become the index of fertility increment; and in fact nitrogen build-up has been shown to be much reduced when phosphorus is lost by leaching or by loss of the surface veneer of the soil by run-off. So far we have gained but a glimmer of the build-up and role of organic matter under pastures, though at least we have progressed away from our tendency to think of a series of unrelated nutrients in our approach to pastures and their fertilisation.

Management

With the ever increasing area of sown pastures, attention has turned to problems of management, in terms both of stock movement and of fodder conservation from pastures. The history of our outlook on management since the mid-thirties is quite extraordinary. At that time we accepted as an article of faith that rotational grazing was a good thing. No one had proved it, but everybody agreed that it was so obviously true that it must be true. Australian workers were the first to challenge this dogma and after being a lone voice for a decade we have gained many supporters of the viewpoint that rotational grazing, divorced from the oft-tangled issues of paddock size and fodder conservation, produces no more meat, wool or milk than set stocking. So we have deleted the ideas of the thirties and forties and we're starting off again with a more or less clean sheet. Perhaps two points stand clear — first, that the production by any herd or flock on an area of ground is closely proportional to the number of animals (this may sound unbelievably obvious but it incorporates new thinking) and secondly that the most profitable rate of stocking is a rate at which each animal is depressed below its potential production by the competition of its companions. This can hardly be applied in areas in which conservation of the vegetative cover is a prime consideration — on sub-alpine lands or in arid and semi-arid pastoral areas — but where heavy pressure on the pasture gives no erosion dangers and where conserved fodder provides a buffer for lean periods, it promises to add very considerably to production per acre.

The future of our pasture lands

In this year of grace 1960 we have some 40 or so million acres rising in fertility under the influence of pasture legumes and fertilisers. What is their future?

Throughout the earlier part of this quarter century the vast majority of those engaged in pasture improvement have regarded the successful establishment of the pasture as a final target, an endpoint. Costs are heavy in terms of clearing, fencing, water supplies, machinery, seed, fertiliser and stock and it is wholly understandable both in economic terms and in those of personal effort that this development should be viewed as a complete operation, to be succeeded by purely maintenance activities.

If one accepts the extreme conservationist viewpoint, as many still do, then lands lying beneath pasture are a fully protected resource. They conform to the ponderous edict of the thirties that farming is a way of life . . . that it is a solemn duty to pass on fertile lands as a heritage to our children. But in Australia we farm for cash . . . the fertility of the soil is the source of cash, and subject to the system being stable, the more fertility we can convert to cash the better. If we apply this brassy but quite scientific philosophy to our pastures, then it is certain that maximum production will be gained if the chemical and physical fertility built under pastures is partly cashed by

cropping, re-built under pasture and cashed again. Some areas will be too steep, some susceptible to erosion, but great tracts of more or less level lands under improved pastures can and are being cropped. Especially in Western Australia and to a less degree in all other southern states, areas formerly devoted wholly to stock raising are being cropped to oats, barley and sometimes wheat. Excellent yields are being obtained and this is obviously the new era, in which built-up pasture lands progress towards mixed farming. Much needs to be done to help these trends. Cereal varieties bred for traditional wheat lands may well be unsuited, and probably *are* unsuited, for these better rainfall areas. We must look for a greater range of crops, both for cash and fodder; and inevitably there will be movement towards smaller properties and more diverse and more secure agriculture.

CHANGES IN CROP PRODUCTION

Cereal rotations

Our principal crop is cereal grain and it is therefore appropriate first to consider some applications of science in grain production. Great changes in land use have occurred in our cereal areas, changes which are clearly the integrated expression of economic and technical factors, rather than the result of planning at a national or local level.

In the thirties the fallow, the use of superphosphate and of varieties derived from Farrer wheats were the basis of wheat production, three factors which had rescued the industry from its years of despair around the turn of the century. Wheat-oats-fallow had become a common rotation — sometimes with a year of 'rest', of volunteer pasture, while in many areas the simple wheat-fallow rotation was still general.

We were very ignorant of what we were doing. The fallow was regarded as having its value in water storage and the emphasis was on repeated cultivation and on weed destruction. Awards were given for the 'best fallow', for land grossly over-cultivated, burning up its organic matter and lying nude to the ravage of heavy rains. Statistical studies showed that yields were trending downwards in most wheat areas as nitrogen became depleted and structure destroyed. Two things happened in the thirties to alter this outlook on 'clean fallows.' First, the Soil Conservation Service of the United States awoke the world as never before to the loss of fertility, loss of resources, and loss of land resulting when unprotected soil surfaces were exposed to wind or water. Their researches and their telling propaganda had their effects in Australia. Soil conservation services were established in all states and we adopted without reservation Lowdermilk's Eleventh Commandment — "Thou shalt inherit the holy earth as a faithful steward, conserving its resources and productivity from generation to generation . . ." The bare fallow, the ultimate in soil exposure, was recognised as a prime source both of water and wind damage and this meant that the wheat-fallow rotation was critically examined. In several states active steps were taken to move farmers from over-cropped marginal areas, from parts of the Mallee of Victoria and South Australia and from the western Riverina of New South Wales. Holdings were merged to give greater size and cereal rotations were based on long periods of ley.

The other development affecting our view towards fallow was that research on Australian soils had shown that the nitrification of organic matter in the fallow was often as important to subsequent yields as was the storage of water. At the Waite Institute, the enormous response to nitrogen by oats on stubble land was contrasted with the non-response by cereals on fallow. Workers at Rutherglen showed that excellent crop yields could be secured after subterranean clover ley, without recourse to fallow.

And so the emphasis moved from fallow to leguminous ley as a source of nitrogen.

Then World War II created a new environment. The United Kingdom wanted meat, dairy products, dried fruit, sugar and any other 'concentrated' foodstuffs. But it proposed to grow wheat at home or to import it from nearby Canada. So wheat growers in Australia fell to the bottom of the priority list

for manpower and for all scarce materials, for fertiliser, machinery, fencing materials and all other needs. The area of wheat fell from 14.3 million acres in 1938 to 7.9 million acres in 1943/44. This meant a greater acreage of pasture and increased production of wool. There was a temporary return to pre-war acreages in 1947-48 but thereafter the steeply rising price of wool kept down wheat acreages and created an environment in which the value of ley pastures was fully realised by wheat growers. Experimental findings showing the influence on wheat yields of the nitrogen added by pastures were now confirmed over great sectors of the wheat belt, so that in cereal areas as in grazing districts, this became the pasture era. Wheat yields in the fifties were 45 per cent. greater than those of the thirties. Three legumes have been of especial importance, subterranean clover in districts more favoured for moisture, barrel medic where the season is shorter and especially on alkaline soils, and lucerne on a variety of soils in all wheat states other than Western Australia. This species picture on cereal soils is certainly incomplete; there are still districts with no particularly satisfactory legume and the testing of additional material such as rose clover (*T. hirtum*) and cupped clover (*T. cherleri*) continues.

The recognition that leguminous leys can do more than a fallow for nitrate status of the crop has been accompanied by an appreciation that the ley builds organic matter and improves structure, while fallow does the reverse. Yet the fallow necessarily continues in drier cereal districts or those with summer rainfall such as the Darling Downs, because here the conservation of water equals or exceeds nitrification in its importance. But fallow practices have changed, with emphasis on a 'trashy' surface better protected from wind and water.

Despite great changes in rotations, land use in many cereal districts is still in a state of flux. There are some regions where exploitive rotations are still in general use, where the pasture ley has yet to find its place. And many wheat growers ask whether grasses are worthwhile in cereal areas, and if so, is there a role for perennial grasses? Are short rotations such as barley followed by a single year of barrel medic as good as longer rotations with long ley periods? How long should lucerne be down? And in particular does greatly enhanced nitrogen status reduce susceptibility to drought? There is some evidence that it does, presumably by permitting fuller root exploration.

The changes in wheat farming have been paralleled in barley and oats production which have been subject to the influence of similar shifts in land use and are often grown in the same regions. There has however been a substantial trend especially in South Australia from wheat to barley in marginal areas, a trend influenced both by prices and by the success of barley in these regions. This use of barley is entirely in conformity with practice in older cereal areas of short season, such as the Saharan fringe of North Africa or the high level limits of cultivation in the Himalayas and it seems likely to be a permanent shift unless there are marked changes of price relationships.

Fertility and conservation

The improving nitrogen status due to pasture leys carries important implications in quality as well as yield. In our wheat production the effect cannot be other than favourable, a tendency for rising protein content of the grain and improved baking quality. On the other hand the rising nitrogen status of the soil is not without potential disadvantage in the production of barley for malting purposes. Here the maltster seeks a grain well filled with starch and of low nitrogen content. There are indications that some traditional districts for the production of malting barley are already yielding crops which though heavier are of less desirable quality because of high nitrogen content. However this relationship is by no means well established. Because the maltster's requirements are based largely on empirical considerations, because within the range of his experience he dislikes nitrogen above certain low levels, it is natural enough that he should condemn high nitrogen for all varieties and circumstances. However it is

certain that the suitability of barley grain for malting cannot be expressed so simply and that when more specific biochemical criteria are available, it will be established that nitrogen content and malting quality show no perfect inverse relationship.

Hand in hand with the emergence of the clover ley as the key to better cereal farming there has been a growing emphasis on reduced cultivation. The clear recognition of what now seems obvious—that it is cultivation and not the growth of a crop that destroys soil structure—has led to a general decline in the number of times a soil is hit by implements. Reduced cultivation is possible because of modern weedicides; certainly we must also examine more fully the 'plough-plant' techniques in which the initial ploughing and the planting are done in a single operation. It is here that a disability of perennial grasses in the ley may be apparent — that they add seriously to problems of seedbed preparation.

All these changes in our wheat farming have been in conformity with policies of conservation—better structure due to leys, reduced susceptibility to erosion. But as already discussed we must adopt policies not only of conservation but also of maximum production. An example of a wrong viewpoint on conservation is the general condemnation of stubble burning as bad in all circumstances. In fact however, current evidence suggests that provided burning creates no erosion hazard (in some areas it does, in many it does not) then the best thing to do with a bulk of useless lignin is to get rid of it by fire and thereby gain increased yields.

Some similar thoughts are developing regarding soil conservation outlook generally. In the thirties and forties there was great emphasis on physical techniques to save and restore damaged lands; on graded banks, pasture furrows, spillways and contour cultivation. These made, and continue to make, an important contribution, sometimes converting quite derelict lands to a high level of crop or pasture production. But soil conservationists recognise, as do other agriculturists, that the final answer to erosion is sound land use with soils held in good physical and chemical condition. Sometimes first-aid action may be needed—to check an incipient gully or control a drifting paddock—but good agriculture includes effective soil conservation and these are rarely separable activities of man. It is again legumes and fertilisers which provide the principal means of increasing output from our cereal lands and simultaneously of improving the stability of the soil. In these circumstances there can be no advantage, and perhaps a good deal of disadvantage, in having the agency for soil conservation separated from the department of agriculture as is still the case in some states.

Cane and other crops

If we turn from winter cereals to the more intensively cultivated crops, the progress towards higher yields has been by different means. The sugar industry, commonly regarded as the most efficient crop industry of the Commonwealth (this despite harvest techniques of the sickle era), has depended on better varieties, successful insect and pest control and improved fertiliser practices for raising sugar yield per acre by over half a ton or about 23 per cent. since the mid-thirties. Fertilisers and not legumes provide most of the nitrogen; and the consumption of nitrogen fertiliser on this crop is no less than half the Commonwealth total. Cane production appears to be a stable industry in the sense that production is being sustained and increased. Though the improved varieties and pest and disease control may be concealing the true trends in soil fertility, it is quite likely that a satisfactory equilibrium relationship of organic residues, nitrogen supply and crop yield has been attained. Here then is the alternative approach to cropping where grazed swards are not suited to the land use pattern—the use of nitrogenous fertilisers combined with minimum tillage (a planting cultivation for sugar is given only once in four years) and the return of a considerable quantity of crop residues as green manure and in the bulky root system of the cane.

This situation with sugar has been contrasted with the decline in productivity of

maize yields in many areas, notably on the Atherton Tablelands. Here nitrogen supplies are quite neglected, with no use of fertilisers and little use of legumes. This is obviously an unstable relationship, or more correctly, one in which stability will be reached only at low levels of yield. It is clearly necessary that we should ask for many of our crops the simple question, what is the source of nitrogen? If the reply is 'the virgin organic matter of the soil' then something must be done — either fertiliser nitrogen or a legume must be provided, and probably other nutrients also. Continuous cropping is not necessarily an evil thing but it cannot be practised unless soil organic matter status, structure, nitrogen supply, tillage practices and the return of residues are in such relationship as to give an equilibrium at satisfactory levels of yield.

Many practices have contributed to our progress in raising the yields of our crops, notably improved varieties, better machinery and cultural practices and weed, pest and disease control. For most crops the main factor has been better nutrition.

PROGRESS IN ECOLOGY

Surveys

During the thirties and forties a good deal of work was done on the descriptive ecology of natural vegetation, usually with principal emphasis on the vegetation pattern but sometimes with equal attention to soils and their relationships to plant distribution. In some instances direct use was made of this information as a basis for land settlement; thus the surveys of the vegetation types and associated soils of the upper south-east of South Australia enabled selection of those areas likely to prove successful for pasture development. Even in areas where no immediate use has been made of the data, vegetation surveys have provided a valuable permanent account of fast-disappearing natural communities. Interest in this sort of work is weakly sustained and it seems that our native vegetation may be cleared or displaced before any reasonably complete record of its distribution has been gained. While it is understandable that experimental ecology should attract many workers from the more descriptive phases of their discipline, it is nevertheless unfortunate that the recording of natural communities for the whole of Australia is not proceeding more rapidly. Agriculturists in Europe frequently seek to reconstruct the picture of the former vegetation cover as an aid to interpreting present-day patterns of crop and weed distribution but often they can do little more than speculate. In Australia the schools of botany of the universities have opportunity to make a valuable contribution while description of most if not all natural communities is still possible.

Perhaps the most notable surveys related to plant production and utilisation have been those of the inland areas of arid and semi-arid climate and of the monsoonal regions of the north. There has been much drivel talked and written about these regions, with opinions ranging from "let's leave it to the kangaroos" to that of an overseas visitor who saw the country after rains and declared "Alice Springs will become another Omaha". It was into this factless controversy that the C.S.I.R.O. Division of Land Research and Regional Survey moved in 1946, not with further opinions but with surveys based on science, jeeps and damper. The approach was new in Australian surveys, since it depended on the multiple criteria of geology, hydrology, soils, climate vegetation and land use if any. Great blocks of country, up to 50,000 square miles in extent, were taken as survey units and then, by traverses which sometimes involved exploration as well as examination, the region was divided into "land systems", units which had a common quality in their potential for land use. The emphasis in particular land systems might be on topography, on vegetation, on soil, but all would be reviewed together in drawing the major boundaries.

Survey data have been supplemented by experimentation with both crops and pastures at Katherine and on the Ord River. The emphasis has been on species and nutrition, but has also included precise studies of these environments, especially of water relations in soil and plant and of atmospheric factors.

The application of agricultural science in these areas is very recent, but we already

have a new appreciation of our less favoured areas, and of their climate and soil. In the monsoonal regions of the north, short-season crops such as peanuts and grain sorghum have technical promise on natural rainfall but still face economic problems. Various sown pasture plants, notably Townsville lucerne, have contributed both to the bulk and quality of feed in experimental grazings. All progress of this kind can now be viewed against a knowledge of the possibilities and the limitations of the environment, so that a single success creates no illusion of Eden, nor a failure black despair. In the areas where artificial or semi-natural irrigation is possible, there are of course wider prospects, with rice already being produced commercially at Humpty-Doo and with cotton and other crops doing well in experimental plantings on the Ord River. All in all the progress of knowledge of the centre and the north in the past 15 years is most noteworthy. The definition of potential still lies ahead.

The use of water

A most important landmark in our understanding of the plant and its environment lies in Penman's work, partly done in Australia, on evapotranspiration. Formerly we had supposed rather vaguely that plants had a sort of built-in mechanism for transpiration, that the ratio of transpiration loss to dry matter production was of itself biologically meaningful. Penman emphasised and formulated mathematically (though not without some inescapable empiricism) the concept that a certain quantum of energy reaches a crop surface as solar radiation, and that the energy not reflected and not used in photosynthesis must be dissipated in some other way. Transpiration is simply a process of evaporative cooling which dissipates this load of energy and prevents disastrous over-heating of the leaves. The consequence of thinking of an acre of crop as an acre of energy-receiving surface is that whether the surface is that of a forest or a crop which has a meagre though complete cover, or a crop which is heavily foliaged, the use of water for transpiration will be much the same. After photosynthesis has utilised a varying but small percentage of the absorbed radiation, the balance of energy remaining to be dissipated will not vary very much and hence, provided water is freely available, loss by evapotranspiration must also tend to constancy in any continuous cover of foliage, be it light or heavy. This is a major change of outlook on water use by our crops and one which has especially influenced our viewpoint in Australia.

Study of water use by our native pastures has given the surprising finding that they do not use all the water entering and retained in available form in the soil. For example, a *Chloris-Danthonia* pasture studied for four years did not at any time dry out the soil to wilting point to a depth of two feet. On the other hand a sown fertilised pasture dried the profile to three feet when hot rainless conditions were experienced. Thus it would seem that the native pastures are not adapted primarily to the deficient level of water supply but rather to the even more deficient level of nutrient supply. Low water use by native pastures is presumably associated with the root distribution, the characteristics of the foliage and the high proportion of bare ground.

Another interesting exploitation of unsuspected reserves of water is through the use of *Hyparrhenia hirta* as a pasture plant in the Mediterranean sector of Western Australia. This summer-growing perennial grass, thriving in a region of winter rain and summer drought is more productive than typical Mediterranean species because it is able to tap water stored deep in the soil. Problems of establishment remain to be overcome before commercial use is possible, but this departure in "species philosophy" for this region is of much interest. It is because of the low production potential of our native grasses, their lack of capacity to utilize more generous regimes either of water or nutrients, that they hold little or no prospect for use in high producing pastures. The pleas made for the fuller study of these native plants as potential sown species are unwarranted.

We know all too little of the relationship of nutrient level and water supply of cultivated crops under Australian conditions. A nitrogen deficient crop may successfully mature a light crop of grain. What will be the effect of added nitrogen? As we have clearly seen from the adoption of ley farming, improved nitrogen status has given markedly increased yields from the same water resources—presumably a consequence of a more extensive root system, able to explore more soil and thus to maintain a greater photosynthetic area of leaves or the same area of leaves for a longer period. Even in dry years, this relationship seems broadly to have held. Yet high nitrogen due to previous ley or to fertiliser is recorded also as inducing such an early leafiness as to deplete the water supply and endanger grain production. Here is a whole complex of factors calling for full study in our cereal areas—the inter-relationship of nitrogen status, root development, water supply, leaf area, transpiration and dry matter production.

Weed control

Ecological studies of weed problems have tended to suffer an eclipse in recent years, not because they have been unproductive but because of the spectacular success of modern weedicides. In earlier years when such substances as the arsenicals and sodium chlorate were the best weedicides available, research workers on weed problems emphasised that weedicides were rarely more than a palliative and, that unless the environment were changed, the weed, even though checked, would resume its former status. Modern weedicides have led to a considerable modification of this view. In some circumstances, such as the control of cruciferous weeds in cereals and of weeds in horticultural crops, the use of weedicides may be so cheap, so selective and so efficient, that without any change in the methods of production, the weed can be held successfully in check or even eradicated. No alteration of the environment is necessary. But there is a danger that the very efficiency of these weedicides may discourage the all-important ecological approach to weed control, even in instances where it offers great potential rewards. With several species the value of competition by useful pasture plants has been clearly demonstrated and has been incorporated into practice. Skeleton weed (*Chondrilla juncea*) is greatly reduced by competition from lucerne, St. John's wort (*Hypericum perforatum*) by subterranean clover, onion weed (*Asphodelus fistulosus*) by perennial pasture plants, either grasses or lucerne and so on. Opportunities exist for similar approaches with many other weed species.

Weed control through insect parasites has been somewhat disappointing during this era, though partial success has been achieved in the control of St. John's Wort, Noogoora burr (*Xanthium pungens*) and Lantana (*Lantana camara*). However no one can doubt the value of this approach to weed control, especially for weeds of extensive grazing lands where the use of weedicides or the establishment of competing plants is uneconomic. All forms of biological control, whether by competing plants or parasitic insects are eventually more satisfactory than mechanical methods or the use of toxins.

Crop studies

In our ecological studies of individual species the plant we understand best in the Australian environment is neither a crop plant nor a weed. It is symptomatic of our emphasis on pasture development in the last few decades that we know more of the ecology of subterranean clover than of any other plant. The published studies on this species far exceed those for wheat and this is especially true in ecology. We have a substantial appreciation in subterranean clover of the influence of water relations, daylength, and high and low temperatures on flower initiation and seed production; of factors influencing hard and dormant seed; of the occurrence of nutrient deficiencies; of germination and growth in swards and so on. Though we are still far from a full understanding of its ecology, the progress made with subterranean

clover is enough to emphasize by contrast how little we have done on the ecology of the wheat plant or of other crops in Australia. Reference has been made to the inadequacy of the research on the water-nitrogen-dry matter-transpiration complex in cereal production, and this is but a single example. What of nutrient-light studies in sugar cane, a crop which gives classic opportunity to exploit sunshine and CO_2 in sugar production? How little we know of tuber development by potatoes in our warmer climates, or of climate and barley quality. The new availability of industry monies for work specifically on wheat and tobacco, on barley and stone fruits will have its effect in stimulating ecological research on our crops to parallel that on our pastures.

THE PHYSIOLOGY OF CROPS AND PASTURES

Light

Plant workers have long been conscious that records of environmental conditions given by standard weather instruments do not provide an account of conditions within a crop, and this has brought into being the study of micrometeorology as it relates to crops and their growth. In particular it has been realised that the light intensity above a crop gives practically no account at all of the light regime of the majority of the leaves. Physiologists have long established that as the light supply to an individual leaf rises above a moderate level the photosynthetic activity increases no further; the earlier tendency to extrapolate from this finding on the isolated leaf to the whole foliage of a crop has been seriously misleading, for we now know that in a fully leafed tree or heavily foliaged crop, the stronger the light the greater will be the number of "saturated" leaves and and the greater the plant growth.

United Kingdom, New Zealand, Russian, Japanese and Australian workers have been the principal contributors to the studies of leaf area and light interception. It has been shown that there are three non-environmental factors influencing the rate of development of leaf by a germinating crop or annual pasture—the genotype, the number of seeds and the size of seed. The genotype influences relative growth rate. The number and size of the seeds directly govern the area of photosynthetic tissue displayed to sunlight by the population of seedlings. This leaf area, initially the cotyledonary area, is the capital invested in the growth process. Thereafter the absolute rate of growth (lb per acre per day) increases as the leaf area rises, but only until the canopy becomes so dense that the heavily shaded lower leaves are respiring more dry matter than they are contributing by photosynthesis.

This field of endeavour holds great prospects in agricultural production—the more precise study of the thesis that agriculture is essentially the exploitation by man of the process of photosynthesis. It is surprising how little we have considered this simple proposition. To take an example—wheat breeders invariably rate the production of their varieties by harvesting the grain—so many pounds per plot or bushels per acre. But equal yields may arise in two ways. The first variety may be outstanding in its rate of photosynthesis, either because it displays a lot of leaf or disposes it to intercept light efficiently, or because it fixes more CO_2 per square centimetre of leaf. A second variety may be less efficient in these respects so that it produces less dry matter per acre. On the other hand its ratio of grain to total dry matter may be very high so that its yield of grain is as great as that of the first variety. (Nichiporovich the Russian physiologist calls this ratio of economic product, be it grain, fibre, fruit or root, to total dry matter the "Coefficient of Efficiency", but a more explicit term here suggested is "The Harvest Index".) Thus one variety has high dry matter production, the other a high harvest index. Surely it may be that if cereal varieties or other species were assessed in these terms, a hybridisation program could combine these attributes to a degree enabling substantially enhanced grain yields. This principle is being tried in at least one Australian programme, possibly the first anywhere.

Watson of Rothamsted has recently issued a challenge to the plant breeder. In effect he says this—The far greater production by the modern, bred variety of sugar beet compared

with the ancestral wild beet is due only to a different disposition of the leaves, giving more efficient use of the light and thereby a greater rate of photosynthsis per plant. No magic, just more upright leaves instead of a rosette. If this is so for beet, we can ask if there are other cultivated plants in which a different disposition of the leaves would add greatly to yield. Another study in Australia and overseas in relation to photosynthesis is that of the contribution to grain yield by the cereal ear. The older idea that annuals grew until they flowered, and then poured all their stored nutrients into the developing seeds is not merely misleading—it is seriously wrong. Similarly the census counts made in so many agronomic studies—tiller counts, ear counts, and so on—while by no means without value, have all too often been treated as though they were the cause rather than the expression of yield. To say that the yield is equal to the number-of-plants x tillers-per-plant x ears-per-tiller x grains-per-ear x weight-per-grain and therefore that these things are important, is a mere syllogism. It takes us nowhere. We now know that 20-50 per cent. of the dry matter of the grain is contributed by the photosynthetic surfaces of the ear and that over half of the remainder is derived from the photosynthesis of the leaves after the ear has formed. Only 20 per cent. or thereabouts is derived from photosynthesis prior to the emergence of the heads. This means that the critical queries regarding the production of the grain of any cereal variety are not How many tillers? or How many ears? but —What is the area of foliage at flowering? How long is it going to be functional? What is the surface area of ear? These are the criteria which give new prospects for both genetic and environmental studies.

Reserves

Australian physiologists and agronomists are interested also in the evaluation of reserves as affecting survival and production by pastures and crops. In the past there has been an easy assumption that a perennial grass with heavily swollen basal nodes will eventually mobilise these stored materials to give earlier and better production, that the well-filled seed will transfer its nutrients to the seedling and so forth. But these comfortable views seem destined to be shaken and perhaps dislodged. Work on subterranean clover, for example, shows that while larger seed reserves will enable emergence from greater depth, they do not help the seedling to grow any faster once it has displayed its cotyledons to the light. It may well be that heavy reserves in the butts of perennial grass emerging from dormancy will permit the more rapid appearance of the first few square centimetres of leaf — but after that, the substantial unused reserves may serve no further purpose—just as the potato set, once it has produced a little foliage, is destined to become a rotting pulp of unused reserves. It is important that we should learn a great deal more on this subject. Writers on pasture management speak of reserves far more than of the photosynthetic surfaces of the sward but it is possible that this is a quite wrong emphasis.

Development

One of the greatest contributions to agriculture by the physiologist is the distinction he has drawn between growth and development, between mere increase in the size of a plant on the one hand and, on the other, the processes leading to flowering, production of fruit and, in annuals, senescence. This work, at its beginnings in the thirties, has made tremendous advances, so that we have a substantial understanding of the influence of day-length and temperature on many species and varieties of crop and pasture plants. We no longer expect ryegrass from northern Sweden to flower in Adelaide nor tropical varieties of rice to produce grain in our temperate areas. The Australian contribution in this sphere has been rather small, especially because of the lack of facilities for studies of this kind. Again it is with subterranean clover that we have done most and here we have a *prima facie* understanding of development and its relation to the Australian environment. The study of factors governing development and

fruiting is also allied to those on dormancy. Winter dormancy in such perennials as fruit trees has been extensively studied in the northern hemisphere but there has been no comparable study of either summer or winter dormancy in perennial pasture plants, subjects of interest in Australia. Temperature, length of day and water stress play varying roles but these remain to be dissected.

Australian work in this sphere may be expected to expand greatly with the construction at Canberra of a phytotron of considerable capacity and range, and at many other centres of smaller groups of growth chambers. These studies will provide a new basis for a large part of our agronomic and plant breeding programmes because they will make it easy to observe replicate material in a great range of climates, real and unreal. On the other hand we may hope that these facilities will not tempt the agronomist and plant breeder to evade the complexities of field research and join their colleagues in the warm and paper-fruitful atmosphere of the great indoors.

BIOCHEMICAL STUDIES

The avalanche of contributions to the biochemistry of plants is overwhelming to the layman and specialist alike. Perhaps those of us concerned with the growing of plants can distinguish contributions which have already directly influenced crop and pasture production, contributions which have given understanding to things already known and contributions which open bright prospect of altogether new knowledge, new sorts of plants, new controls of growth and development.

In the thirties Australia had few workers in plant biochemistry and it is only in the post-war era and especially in the 1950's that there has been a great increase in Australian research endeavour in this discipline. It is perhaps because of this earlier meagreness of effort that the application of biochemical findings to Australian agriculture has depended principally on progress overseas. Yet so rapidly are programmes now developing — programmes not only under government and university finance, but also those supported by industry—that we may confidently expect Australia to make significant contributions in the years ahead.

Perhaps the overseas studies of most immediate consequence to Australia in the earlier part of the review period were those of plant hormones, their movement and their influence on cell growth and in more recent years their division and differentiation. Since Went's extraction of the substance which causes the Avena coleoptile to curve towards light and Kogl's identification in 1936 of the simple substance indole-acetic acid, as a hormone, the whole field of plant growth regulators has proved remarkable for its contributions both to biology and to practical agriculture. The array of growth regulators becomes bewilderingly diverse as more and more natural and synthetic substances are shown to affect growth processes. Weedicides, based on those growth regulators which disorganise the normal physiology of the plant, have been discussed earlier. The use of various substances for controlling flowering and fruit setting, for striking cuttings, preventing premature fruit drop and for breaking and inducing dormancy has developed a whole new field of agricultural practice. For horticulturists in particular this panel of controls has substantially altered crop production techniques and there is every reason to believe that future contributions will be no less dramatic in their implications.

A further major advance now seems imminent with the growing understanding of the influence of visible and infra-red light on the day-length response by plants. These differing wavelengths have converse and immediate effects on the direction of a chemical reaction which in turn influences the capacity of plants to flower. Though the biochemistry of these substances is yet to be determined, it seems likely that they may provide a mechanism not only for hastening or delaying flowering by a short span but perhaps for inducing or checking flowering at will. The consequences of such control in agriculture are almost beyond contemplation. At present pineapples can be so regulated by using napthalene acetic acid, but imagine this control applied to field crops generally. During an adverse season the spray-

ing of a crop of wheat might induce premature flowering so that grain is developed before moisture supplies are exhausted. Desirable horticultural plants, normally flowering in a frost-danger period, could be delayed for several weeks. Various perennials might be induced to crop twice a year under favourable conditions of light, nutrient and water supply. And so on.

It is of interest that a major development in Australian plant biochemistry, the work under way at two universities on the amino-acid composition and protein structure of wheat, has been financed by a levy of wheat growers. This sort of development is characteristic of the extreme research-mindedness that has grown among Australian producers during the past two decades. These quality studies are of but three years' standing, but because of the new techniques at the disposal of biochemists they are already breaking new ground. and providing leads on the chemical differences governing wheat strength. An objective of quality studies of this kind is to enable the standard cereal chemistry laboratory or the cereal breeder to discard empirical tests such as blowing bubbles in dough and instead to use meaningful chemical analysis as the basis for the assessment of environmental and genetic influences on quality.

There may be those who feel that the costly work of the biochemist has not yet had the influence they had hoped—that much biochemistry is so far removed from agriculture as to be of little concern to the agronomist or farmer. This viewpoint is very wrong. In 1930 biochemistry scarcely existed in terms of its present knowledge, aims and outlook, and only during the past decade or two have its wonder tools come into being, the analytical centrifuge, modern chromatography, radioactive isotopes, the electron microscope and so on. In this short time the biochemist has developed his beautiful though still impressionist picture of protein structure, he has penetrated towards the chemistry of the gene and has even seen the first distant glimmering of the chemistry of life and evolution. These are remarkable advances which must eventually place at man's command new and more subtle techniques for the control of the growth of plants.

However, all may not be gain for agriculture. The chemist has already challenged the pastoralist and farmer with his synthetic fibres, his dyestuffs, plastics and detergents; these developments will continue and perhaps extend to competition with foodstuffs. In years to come the use of energy, water and carbon dioxide in the synthesis of sugar will doubtless challenge the cane and sugar beet industries, whose product is but a simple chemical substance. Starch will follow and then . . .

It is our responsibility to see that the chemist devotes as great a part of his skills to agriculture as he does to these competing products.

POWER AND MACHINES

This has been the era of disappearance of the horse and its replacement by the tractor—of the substitution of petrol for chaff, grain and bran as the source of energy. In the mid-thirties there were some 1.8 million horses, now there are about 0.6 million, very few of them working on farms; in the same period the increase in tractors has been from about 50,000 to 250,000. By making various assumptions, we can deduce that the tractive power available on farms as a result of these changes has increased five-fold or more during these 25 years. And in addition to tractors, power has increased in many other ways, in self-propelled machinery and as stationary engines and motors for a multitude of purposes.

Most of this additional energy has gone either into land clearing operations or into crop and pasture production, much less of it into immediate work on animal production. Land clearing has proceeded apace by the use of bulldozers, by dragging down forest and scrub with steel chain and log, by the use of "the big plough" on partially cleared lands and by various techniques of burning. Power, ideas, machines—these have been the modern answer to clearing. But in some areas re-

growth problems have been considerable, either because of slovenly clearing techniques or because of the difficulty of killing the native vegetation. In the brigalow of Queensland, the regrowth from ligno-tubers is so vigorous that work has been done on the use of hormone phyticides from the air, and this may prove to be a means of opening these lands.

Increased mechanical power has been associated with a variety of machines which add greatly to the efficiency of farming operations. Some machines have contributed even more and have appreciably changed the pattern of the agriculture. In the first category we have the heavy and the light tractor, agricultural aircraft, pneumatic tyres, 3-point linkage, bulk handling equipment, spray equipment, harvesting machinery for cereals, potatoes, cotton and peanuts and machinery for vegetable production. In addition the timing of many agricultural operations has been greatly improved because they can be done so much more quickly—the critical cultivation for seedbed preparation, the sowing of the crop, the harvest to beat predicted rains or winds, and other such simple but important races against time. Machines which are affecting the very nature of agriculture include aircraft able to apply fertiliser and pasture seeds on areas too steep for ground machines, the sod seeding of legumes into tough grassy swards, and the one-man baler and the forage harvester with their enormous impact on fodder conservation on the smaller farm. These are not just making work quicker or more efficient—they are doing things not done before and thereby making agriculture more secure and profitable.

Perhaps only the inventor can predict the role of new machines in the years to come. Nevertheless, we can say rather randomly that crops will be grown with minimum tillage, with implements designed to make a reasonable seedbed without excess pulverisation of soil; machines will make still further progress in handling fodder for conservation, in precision spraying and in finely adjusted sowing; and the Australian sugar crop will be the first mechanically harvested sugar crop in the world. Indeed on past experience we can expect power and machines to make an ever increasing contribution to Australian agriculture by doing things both better and faster.

RISING PROSPECTS

We can return to the premise that this past quarter century has been the pasture era. This will be accepted as a fair analysis in all states other than Queensland, where little progress has yet been made with pasture improvement. The trend towards better nutrition both of pastures and crops will continue strongly, probably with the same basis of legumes and fertilisers in southern Australia, but with nitrogenous fertilisers playing an increasing part in the south and perhaps assuming a major role on pastures as well as crops in our summer rainfall areas. We can hope to see spectacular advances in plant growth in these sub-tropical areas, initially through pasture development on better soils, perhaps followed later by a wave of crop expansion.

New understanding of water relationships and of photosynthesis of plants in the field will influence agronomists, nutrition workers and plant breeders alike. And progress in the control of plant development by hormones will extend from horticultural plants to field crops. But technical advances will not alone be enough to permit maximum progress in plant production. Since World War II capital investment, mechanisation, better roads, favourable taxation levels and good prices for most products have been factors of great importance and these will continue to be a critical part of the over-all prospects.

Efficient plant production will doubtless continue to be the main factor in efficient animal production, whether animals feed on pastures or conserved fodders, on grain or protein concentrates. This relationship receives inadequate recognition, despite its particular importance to Australia where serious stock diseases are largely controlled, where stock numbers rather than individual production levels have for several decades been the key to rising output and where numbers are likely to continue to play the dominant role.

We now have a great elasticity in our cropping program, especially in cereal production. In the traditional cereal areas further substantial increases in yield are possible; in the new lands developed to satisfactory fertility levels from low fertility scrub and native pasture, great areas can be turned to cereal production. We could look for the doubling of our grain production or even more if it were warranted by demand.

Plant production in Australia has tremendous prospects. What we mainly have to do is to keep on providing more nutrients and developing plants capable of using them.

AGRICULTURAL SCIENCE
IN AUSTRALIA 1935-1960

ANIMAL PRODUCTION

E. J. UNDERWOOD

The animal industries of Australia have grown steadily over the last 25 years. Total sheep numbers increased from 112 millions in 1935 to 153 millions at the present time; beef cattle numbers from approximately 10 to 12 millions; dairy cattle from 3 to nearly 5 millions and pigs from 1.1 to 1.3 million. Moreover, these increases in numbers occurred during a period when slaughterings of sheep and lambs and of cattle and calves for local consumption and export had each risen by between two and three millions per year. They were accompanied, in some cases also, by a slight overall improvement in productivity per animal. Only in wool production, however, in which an average increase of about one pound per head occurred, was this improvement appreciable.

Many factors have been responsible for developments in animal production of this magnitude. Great new areas have been opened up; spectacular improvements in the quantity and quality of pastures have taken place; numerous stock diseases and pests have been brought under complete or partial control; animal improvement has proceeded steadily as a result of planned breeding and selection; whilst animal husbandry—the nutrition and management of flocks and herds—has begun to emerge from an art based largely on experience and empirical observation to an art based on a vastly improved scientific understanding of the physiology of the animal and its reaction to the Australian environment.

Some conception of the increased technical knowledge in animal production available to farmers and graziers may be gained from the simple fact that 1935 marks the date of the discovery of the first naturally-occurring trace element deficiency, that of cobalt, in grazing stock in Australia. Almost the whole of the remarkable work on other mineral deficiencies and toxicities and their control in the field has taken place since that time. It should also be appreciated that, prior to 1935, little was understood of the peculiar nutritional requirements of the sheep for maximum rate of wool growth; the qualitative disabilities of the grains and roughages available for maintaining sheep and cattle during drought were unknown; pregnancy toxaemia in ewes and neo-natal mortality in lambs had not been investigated in this country; the nature and significance of the breeding and non-breeding seasons in ewes and the environmental factors affecting fertility were not realised; and artificial insemination in dairy cattle had not begun.

The purpose of this article is to present a picture, in outline only, of these and other

Australian scientific advances in the field of animal production and to give some idea of their implications for our animal industries. A great deal of this work has been carried out by the animal research divisions of C.S.I.R.O. and of the State Departments of Agriculture, although in the last decade the university faculties of agriculture and veterinary science have emerged as major contributors and this trend is likely to continue. In sheep and wool research, the C.S.I.R.O. has played and is still playing an outstanding role. In this it has been very greatly helped by the resources made possible by the provisions of that far-seeing measure the Wool Promotion Act of 1946.

WATER FOR LIVESTOCK

The importance of adequate supplies of good quality drinking water for stock needs no emphasis in Australia, with its unenviable reputation as the driest of the continents. Furthermore, as the density of the livestock population continues to rise, in consequence of pasture improvement and better husbandry practices, this problem is likely to become more critical. For this reason the recent development by C.S.I.R.O. of the Mansfield process for substantially reducing the large evaporative losses of water from surface catchments by means of cetyl alcohol films must be regarded as an important and timely advance.

Problems relating to the quality of stock water supplies are mainly those of high salinity and high fluoride levels. The former are widespread throughout the continent and the latter appear to be confined to many of the thermal bicarbonate waters of the Great Artesian Basin of Queensland. The long-term experiments of Peirce with sheep have shown that (1) this species, given a period of gradually increasing concentrations, will withstand levels of sodium chloride in their drinking water as high as 1.3 per cent. for long periods without any adverse effects; (2) higher concentrations than this are detrimental, mainly due to reduced food consumption; and (3) intakes of saline waters are significantly higher than those of non-saline waters under the same conditions.

This worker has also demonstrated a very high tolerance of sheep for fluoride-containing water when consumption does not commence until the animals are 10-11 months of age or older, and when its intake is intermittent and the grazing conditions favourable. Under such conditions, as occur in the southern Australian environment, no adverse effects were observed, other than lesions of fluorosis in the teeth, from levels of fluoride up to 20 ppm F, although 10 ppm F was sufficient to reduce production when it was consumed from before birth and throughout life. Under Queensland conditions, by contrast, Harvey found that fluoride concentrations in the drinking water of 2 to 5 ppm result in damage to the teeth sufficient to prevent or limit the capacity of the sheep to gather or masticate fodder. It is this impairment of grazing efficiency which is directly responsible for the reduction in wool production and the increased mortality of lambs in the fluorosis areas. Dietary mitigation studies have not been successful but Harvey has devised management practices, based on maximum protection for the young animal and alternating periods of exposure to and protection from the fluorided waters, which can materially reduce the incidence of the disease.

DROUGHT FEEDING

Recurrent droughts, involving considerable stock losses, are a conspicuous feature of large areas of Australia. The hand-feeding requirements and procedures necessary to avoid, or minimise, these losses have been investigated by Franklin and associates in New South Wales and Morris in Queensland. With both sheep and cattle diets ranging from poor quality roughage to all-grain rations have been shown to be effective and economical for this purpose, provided that their qualitative deficiencies are remedied. Satisfactory

maintenance of sheep during drought can be achieved with as little as 10 lb per head per week of good quality hay alone, but low-quality roughages require supplementation with a protein concentrate and cereal grain diets with calcium, preferably as finely ground limestone at the rate of 1 to 1½ per cent. The severe calcium deficiency which develops in lambs, weaners and lactating ewes, fed these high grain diets without supplementation for the prolonged periods which may be necessary in times of drought, was convincingly demonstrated by Franklin. Calcium deficiency in this species was shown to be characterised by stunted growth or loss of body-weight, hypocalcaemia, lowered wool and milk production and gross abnormalities and impairment of the development of the teeth, followed by death in extreme cases.

The considerable potential of "bush" hay and sorghum silage as drought fodders for beef cattle was demonstrated by Morris, who further established that protein is the principal deficiency limiting their usefulness. Supplementation of these roughages with urea, at the rate of 2.5 oz per day for cattle and 8 g per day for sheep, was found to be a highly satisfactory, safe, and economical means of increasing their value.

The provision of salt supplements has been clearly shown to confer no measurable benefits upon sheep consuming drought rations. This finding is of great interest in view of the widespread use of salt licks for stock and the well-established fact that such supplements are necessary when cereal grain diets are fed to pigs, poultry and milking cows. With sheep on high-grain fattening diets, on the other hand, the value of additions of common salt has definitely been demonstrated. McClymont and co-workers recorded improved food consumption and efficiency of food utilisation, with significant increases in the body-weight gains of young Merino wethers, when 0.25 per cent. salt was added to such diets.

A further nutritional deficiency, shown to be a significant cause of loss of breeding ewes and young sheep under drought feeding conditions, is that of vitamin A. Earlier studies by Gunn had demonstrated the importance of this nutrient in maintaining spermatogenesis and semen quality in rams, and Underwood and Peirce had both established that sheep ingest excessive amounts of carotene (provitamin A) from green grazing, store the surplus in their livers as vitamin A and draw upon these reserves during the dry summer when the herbage and the usual cereal hay and grain supplements (but not silage and good legume hays) are exceedingly low in carotene. Such vitamin A reserves were found to be adequate to tide the animal over the usual summer period but under prolonged drought feeding conditions Franklin observed heavy losses of ewes and of weaners fed the recommended cereal diets, unless additional carotene or vitamin A was provided. A high degree of protection, lasting for several months and resulting in a marked reduction in mortality of both lambs and weaners, was obtained from a single large drench (500,000 International Units) of a vitamin A concentrate given at or near marking or early in the drought period.

Results of great practical value have also been obtained from studies of the frequency of feeding of drought rations. With all sheep, other than ewes in late pregnancy, weekly or twice weekly feeding was found to be more economical than daily feeding and to result in fewer deaths, greater uniformity in body-weight and usually greater total wool production. This important finding means that daily feeding at drought levels can no longer be regarded as sound husbandry. Such feeding practices have been shown to be unsafe, however, when urea is used, because of the dangers of urea toxicity.

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NUTRITION AND WOOL GROWTH

Prior to 1935 it was widely held that the extensive grazings, upon which the Australian fine-wool industry had been largely built, were in some way essential for the successful raising of Merinos and the maintenance of the quality of their wool. Field experiments initiated by the late Sir Ian Clunies Ross dispelled this belief and, by 1937, had shown that such sheep respond to the higher nutritional levels of improved pastures by producing much heavier fleeces with little change in fibre diameter. Since that time many studies ranging from practical field trials to the most sophisticated laboratory investigations have combined to emphasise the profound influence of nutrition upon the quantity and quality of wool grown by sheep and to provide a vastly improved understanding of the complex and peculiar processes by which this animal converts its fodder into the keratin of the wool fibre.

The quantity of wool produced by a sheep is now known to be determined by the total number of functioning, fibre-producing wool follicles that it carries in its skin and by the length and thickness of the fibres produced by the individual follicles. The upper limit of each is determined by the genetic constitution of the animal but the extent to which this hereditary capacity to grow wool is expressed in respect to both total numbers of fibre-producing follicles and to wool per fibre, is greatly influenced by the nutritional treatment received by the sheep, not only while the wool is growing but during late gestation and early post-natal life. Histological studies of the skin, begun by Carter and associates and continued with greater success by Schinckel, have revealed two types of wool follicles, primary and secondary, arranged in groups of three primaries to varying numbers of secondaries, depending upon the breed. The primary follicles are all laid down by mid-uterine life but the secondary follicles, which are 20 to 30 times more numerous than the primaries in the Merino, are laid down from about 85 days gestation to birth and for several months thereafter. Sub-optimal nutrition during this period has been shown by Marston, Carter and others to markedly and permanently reduce the number of follicles which actually produce wool fibres. This is due to the stunting of body growth and development of the animal which occurs, so that the total area of skin upon which wool can grow is reduced, and to an impairment of the development of many of the potential wool follicles into functioning, fibre-producing entities. These limiting effects of under-nutrition during early life on the ultimate wool-producing capacity of the sheep can never be completely overcome. They strikingly illustrate the special importance of nutrition during late pregnancy and post-natal life in the sheep.

The rate of wool growth by the individual functioning follicles is basically determined by the concentrations of appropriate amino acids present in the tissue fluids which surround the follicles. The special significance of supplies of cystine, in view of its high content in wool relative to the levels in herbage protein, has been stressed by Marston and has focused attention on the quantity and quality of protein in the sheep's diet as the principal determinant of wool growth. Numerous experiments demonstrating a response from protein supplements have served to confirm this viewpoint. More recently Ferguson has produced experimental evidence that the growth of wool can be independent of the dietary protein percentage, within the range of 7.5 to 29 per cent., where the diets are isocaloric in nett energy. He claims that, when diets containing more than 8 per cent. crude protein are fed, wool growth responses to increasing intakes of food must be attributed to increasing energy supply rather than to an extra dietary supply of amino-acids. These findings emphasise that both the energy and protein needs of the sheep must be fully supplied if it is to display its wool-growing potential.

Abundant evidence has been obtained that these needs are not met from natural or im-

proved pastures for many months in every year over large areas of the Australian continent. In Western Australia, Stewart and Moir showed that during winter and spring, when the annual pastures were rich in digestible protein and energy, the rate of wool growth by mature, grazing sheep was two to three times that of the summer and early autumn period when these pastures were dry, mature and of low nutritive value. Supplementary feeding, sufficient to make good the fall in available protein and energy, was found neccessary to completely prevent the summer decline in rate of wool growth and the accompanying decline in mean fibre diameter. Similar growth responses from protein and energy supplements fed to sheep grazing dry summer pastures have recently been reported by Allden. The value of urea or urea plus molasses as supplements to low-protein roughage diets in increasing food intake and promoting wool growth has been established by Peirce, Coombe and others.

The most spectacular effect of nutrition on wool growth is that due to copper deficiency. Lowered wool weights can occur as a result of cobalt deficiency or vitamin A deficiency, or of any other condition which limits food consumption, including lack of copper. These are indirect effects, or expressions of an inadequate supply of suitable substrate to the follicles due, in each case, to lowered food consumption. Copper has, in addition, a direct effect on the keratinisation process itself and has been shown by Marston to be specifically involved in the conversion of the free-SH groups of the pre-keratin fibrous protein which exists at the base of the wool fibre to the -S-S- groups of keratin proper. The production, by copper-deficient sheep, of "stringy" or "steely" wool inferior in physical properties and lacking the characteristic well-defined crimp of normal wool, was recognised by Bennetts early in the Australian studies of this element and is now known as one of the most sensitive indicators of copper deficiency in sheep. Extensive areas in Queensland and southern Australia have been defined in which this condition is the only or the major expression of copper deficiency and successful means have been evolved for its prevention and control, either by administration of supplemental copper direct to the animal or through treatment of the pastures.

During the last decade experiments carried out by Ferguson and others at the C.S.I.R.O. Sheep Biology Laboratory on the efficiency of sheep as converters of food to wool indicate that maximum output of wool per unit of food or of pasture—the usual desideratum of the woolgrower—is not necessarily achieved through maximum weight of wool per sheep. By employing varying levels of protein intake, comparable with those encountered in normal grazing practice, it was found that efficiency of wool growth, in terms of wool produced per unit of protein consumed, falls with increasing protein level consumed, the greater the inherent efficiency of the sheep in this respect the smaller the fall. This example of the law of diminishing returns has far-reaching implications in sheep husbandry, the full impact of which will only be seen as further experimentation provides the data upon which practical recommendations can be made. It is already apparent, however, that scope exists for increasing wool production per acre by restricting the amount of pasture eaten by each sheep to less than that required for it to achieve its maximum yield of wool. In practical terms, this means sharing the pasture among more sheep so that each produces less wool but at greater efficiency, although there are obvious limits to such a practice—limits which will vary with the sheep and the environment and which apply only to the production of wool by the mature, non-breeding animal.

HORMONES AND WOOL GROWTH

During the last few years research led by Ferguson at Prospect has established that at least three endocrine glands, the anterior pituitary, the adrenal cortex and the thyroid, have an important influence on the growth of wool. This research, which is only in its early

stages, is designed to go much further than the discovery of which hormones influence wool growth—it is aimed at an understanding of the factors regulating their secretion, of the relation of secretion rate to genetic differences in wool production, and of the role of the endocrine system in environmental influences upon wool growth.

Already appreciable progress has been made. It has been shown that the secretion of the pituitary is necessary for normal wool growth and that injections of anterior pituitary extract or pituitary growth hormone are capable of stimulating wool growth in normal sheep. Whether this means that differences in productivity among individual sheep are due to differences in secretion rate of pituitary growth hormone is not yet known.

Overseas evidence that the thyroid hormone affects wool growth has been confirmed and extended by Ferguson, who found that thyroidectomy reduced wool growth to about half the normal rate; that dosage of normal sheep with thyroxine at high levels is capable of increasing wool growth as much as 40 per cent.; that the thyroid is essential for the completion of development or maturation of the secondary wool follicles; and that more thyroxine is required for the normal development of these follicles than is required for general body growth. The practical possibilities emerging from these important findings and those of Godfrey and Tribe, who demonstrated a significant increase in wool growth from thyroxine implants in sheep fed restricted amounts—but not in those fed unrestricted amounts—of hay, have yet to be evaluated. At the higher dose levels of thyroxine used by Ferguson, deaths from hyperthyroidism occurred and at lower levels the increases in wool growth were accompanied by losses in body weight and by higher food consumption resulting in a reduced efficiency of wool growth. Longer-term experiments may also disclose other adverse effects, such as shorter life span, reduced heat tolerance or poorer reproductive performance.

Evidence obtained so far indicates that the hormones of the adrenal cortex, by contrast, depress wool growth, apparently by direct action on the wool follicle. The possibility that temporary overactivity of the adrenal cortex, in response to environmental stress, may be a factor in the occurrence of "tenderness" and "break" in wool has therefore been suggested. The reduction in rate of wool growth and fibre diameter which occurs during periods of nutritional stress has long been recognised as a major casual factor in tenderness and break. It now seems likely that the activity of the sheep's adrenal cortex can be linked with nutritional and other stresses in the occurrence of these wool faults as it has been in the occurrence of pregnancy toxaemia in ewes.

RUMEN STUDIES

Overseas workers have shown that the vast microbial population of the rumen of sheep and cattle plays a vital role in the nutrition of these species, principally through the capacity of the microorganisms to break down the fibrous constituents of plants to the energy-providing fatty acids—acetic, propionic and butyric—and to synthesise vitamins and protein from simpler dietary compounds. Several groups of workers in Australia have studied these processes further, with special emphasis upon their quantitative significance and upon the factors which influence the numbers and types of microorganisms within the rumen.

Moir and associates in Western Australia have developed methods capable of giving a reasonable assessment of the total concentrations of rumen bacteria and protozoa in sheep and by the use of these methods have shown that rumen bacterial concentrations fluctuate diurnally, daily and seasonally, in consequence of dietary changes and probably also of environmental factors such as changes in hours of daylight and ambient temperatures, and that the concentrations are markedly influenced by the absolute and relative amounts of available energy (starch) and protein in the diet, by the dietary source of nitrogen, and by the eating habits or pattern of food consumption of the animal. Rumen protozoal

concentrations were also shown to fluctuate seasonally, although not to the same extent as the bacteria, and to be markedly affected by the pH of the rumen and the feeding pattern of the sheep.

Evaluation of these findings in overall nutritional terms is fragmentary, although some correlations with nitrogen retention and dry matter digestibility have been recorded and evidence obtained that rumen microbial activity can reduce the value to the host sheep of certain nitrogen sources by rapid ammonification and loss of ammonia and can enhance the value of others, e.g. urea, by amino-acid synthesis and conversion to rumen microbial protein. This protein, which represents a variable but often substantial proportion of the nitrogen actually utilised by ruminants, has been shown to be very constant in composition; to have a very similar assemblage of essential amino-acids to that of ordinary herbage protein; to be markedly inferior in this respect, especially in methionine and isoleucine, to such "perfect" proteins as that of whole egg; and to be superior in the same respects to vetch and subterranean clover seed proteins. The importance of an adequate intake of sulphur to the utilisation of urea by ruminants has also been established and significant increases in nitrogen retention and in rumen bacterial concentrations demonstrated in sheep when methionine, cystine or inorganic sulphate is added to urea diets low in sulphur.

Reid and others in Sydney have been particularly concerned with the effect of dietary changes on the products of rumen microbial activity, notably volatile fatty acids, lactic acid and ammonia and their influence, in turn, upon rumen pH. These studies have revealed that the rumen pH of sheep is closely related to the volatile fatty acid level and rarely falls outside the range 5.0 to 7.5, except on high soluble-carbohydrate or starch diets when lactic acid accumulates. Significant changes in the proportions of the three main volatile fatty acids present in the rumen on different types of diet were also demonstrated. Thus on an all-roughage diet the proportions found were 72-76 per cent. acetic, 14-16 per cent. propionic and 10-12 per cent. butyric, whereas on a diet containing 70 per cent. wheat grain the proportions were 63-65, 18-20 and 16-18 per cent. respectively. Significant changes in these proportions related to time of feeding were observed on all diets. These findings imply major qualitative changes either in the rumen microbial population or in its metabolic pattern, in response to changing dietary conditions which affect rumen pH.

Finally, mention should be made of the capacity of the rumen organisms to produce large quantities of vitamin B_{12} and of even greater quantities of physiologically-inactive vitamin B_{12}-like compounds in the presence of adequate cobalt. A spectacular fall in the B_{12}-activity of the rumen contents of sheep, following withdrawal of the supplementary cobalt from a cobalt-deficient diet, was demonstrated by workers in Adelaide. These and other findings mentioned in the section on cobalt deficiency, illustrate the complete dependence of the ruminant upon the microorganisms of its rumen for its supplies of vitamin B_{12} and the dependence, in turn, of the growth and synthetic activity of the microorganisms upon the dietary treatment accorded their host.

NUTRITION OF THE PREGNANT EWE

The importance of level of nutrition during the last two months of pregnancy, when 75 per cent. of the growth of the foetus occurs in the ewe, has been demonstrated by many field and laboratory studies in this country and others. Under-nutrition at this time, especially when the ewe is carrying twin lambs, can result in serious losses from the disease pregnancy toxaemia, sometimes called twin lamb disease or pregnancy paralysis. Following indications from the results of overseas investigations, Underwood and Shier carried out large-scale field trials which established the importance of under-nutrition and demonstrated the practical value of adequate supplementary feeding during the last six to eight

weeks of pregnancy in reducing losses from this disease. However, observations of field outbreaks of pregnancy toxaemia were not always consistent with a straightforward under-nutrition hypothesis and there was little real understanding of the problem until the brilliant studies of Reid and associates on the physiology of the pregnant ewe were conducted during the last decade.

Reid's first finding relates to the fact that the end-products of carbohydrate digestion in ruminants are the lower fatty acids—acetic, proprionic and butyric—rather than glucose as in non-ruminants, although ruminants need glucose within their bodies to provide fuel for their central nervous system, to facilitate the metabolism of acetic acid, and in pregnancy, to meet the energy requirements of the foetus. The latter can be so high, particularly in late pregnancy with twin foetuses, that the ewe develops hypoglycaemia unless feed intake is sufficient to meet the additional demands. The second significant finding is that feed intake at this time may be voluntarily reduced below the level necessary to provide the glucose requirements of ewe and foetus, because the large volume occupied by twin foetuses in the abdominal cavity in late pregnancy causes a marked compression of the rumen, reduces rumen volume and lowers appetite. The third and most recondite discovery of Reid concerns the key role of the adrenal glands. In response to hypoglycaemia this gland secrets hydrocortisone which stimulates glucose formation from body protein and helps maintain blood glucose levels. In severe under-nutrition, with continuing hypoglycaemia, the adrenals enlarge and become hyperactive, the metabolism of the ewe moves towards that characteristic of adrenal steroid diabetes, and the adrenal cortex itself becomes peculiarly responsive to stress.

The hyperketonaemia characteristic of ewes undernourished in late pregnancy was shown by Reid to be a consequence of reduced ability to metabolise acetyl-coenzyme A via the tricarboxylic cycle and this biochemical lesion, it was suggested, is a consequence of the excess cortisol.

Under-nutrition in late pregnancy is thus revealed as an indispensable predisposing factor in pregnancy toxaemia but other environmental stresses, such as inclement weather, disease, transport or even unfamiliar surroundings, are also clearly of critical importance. It is apparent that these investigations have gone a long way towards elucidating the aetiology and pathogenesis of the disease and explaining many previously conflicting aspects of its incidence.

NEONATAL MORTALITY AND GROWTH IN LAMBS

Reliable estimates place the total neonatal losses of lambs in Australia at about four to five millions annually, but only in recent years has the extent of these losses been appreciated and the underlying causes critically investigated. Moule's study of Merino flocks in western Queensland was the first to draw scientific attention to the problem. He found that no less than 36 per cent. of the lambs born died between birth and marking, mostly within the first three days of life—predators and neglect of the lamb, i.e. poor mothering, being particularly implicated. In southern Australia, where predators are less common and husbandry more intensive, losses of this order have also been observed. In fact, Barrett records losses in a Corriedale flock in Victoria ranging, in different years, from 26 to 41 per cent. of all lambs born. In Western Australia, recent surveys of wheat-sheep properties by the Department of Agriculture have disclosed average district lamb losses, based on farmer records which tend to underestimate, of from 5 to 15 per cent., but several farmers in each of eight districts reported severe losses up to a maximum of 57 per cent.

The physiological factors involved in this serious problem are now emerging from the detailed investigations of Alexander, Watson and others. These investigations have shown that lamb deaths in early life can rarely be attributed to abortion or to pathogenic infections but the nutrition of the ewe in late

pregnancy and the climatic environment of the lamb following birth are highly significant, and often related, factors. The importance of adequate prenatal nutrition of the ewe to lamb survival is not a new finding and was, in fact, evident from overseas studies and the field trials of Underwood and Shier, but evidence of the nature of the disabilities imposed on lambs from under-fed ewes represents a new and important contribution to our understanding of the problem.

It is now clear that copious lactation usually commences at parturition, or earlier, in ewes well-fed in late pregnancy, whereas in ewes poorly-fed during this time the onset of milk secretion is often delayed for some hours after parturition and then only occurs at a much lower rate than that of well-fed animals. It is also clear that lambs from very poorly-fed ewes are not only smaller at birth, but they have consistently lower body temperatures, take longer to adjust these temperatures and withstand fasting for a shorter period than lambs from ewes well-fed in late pregnancy. The combination of delayed onset and reduced rate of milk secretion and of impaired development of the heat-regulating mechanism of the lamb is sufficient of itself to greatly reduce the chances of survival in very early life when most neonatal mortality occurs. The solution in this case lies in ensuring that all ewes are maintained on a good plane of nutrition during the critical last six to eight weeks of pregnancy. Where cold, wet and windy conditions occur at lambing, severe neonatal mortality has been observed even with well-fed ewes, due to the much higher energy demands imposed on the lambs by these conditions. In this case, as Alexander and Watson have pointed out, the practical solution lies in lambing at a different time of the year, or under artificial shelter, to provide a milder environment. When lambs from poorly-fed ewes are subjected to such an inclement environment they are driven into negative energy balance, retain their low body temperatures, and become lethargic and disinclined to suckle. It is in such a situation that the most serious mortality is likely to occur. Under-nutrition in late pregnancy has therefore been revealed as a primary, but not an exclusive, casual factor in neonatal mortality in lambs, as it was in pregnancy toxaemia in ewes.

Postnatal growth in lambs has attracted some attention, particularly in relation to fat lamb production where rapid growth and development are essential, although it has not been so intensively studied in Australia as neonatal mortality. Three main factors affecting growth-rate have been established. Excluding breed differences, which are beyond the ambit of this article, these are the birth weight of the lamb, the milk yield of the mother and the climatic environment during the growing period. Thus Underwood and Shier, working with lambs from Border Leicester X Merino ewes mated to Southdown rams, found that (1) each increase of 1 lb in birth-weight reduced the average time taken by single lambs to reach 65-70 lb live-weight by five to seven days; (2) the birth-weight of lambs, especially twins, from ewes very well fed in the last six to eight weeks of pregnancy was significantly higher than that of lambs from ewes poorly fed during this period; (3) the whole of the increased growth-rate of the lambs from the well-fed ewes could be accounted for by their higher birth-weight; and (4) there was great variation in the growth-rate of lambs of the same breeding and birth-weight in different seasons, due, it was suggested, to a varying incidence of wet and cold conditions.

In spite of overseas evidence that the lamb is highly dependent upon the milk obtained from its mother during the all-important first two months of life and that the milk yield of the ewe is greatly influenced by its prenatal, as well as its postnatal, nutritional treatment, few Australian data exist on the factors affecting milk yield in the British breed and crossbred ewes favoured for fat-lamb breeding. Recent studies by Lloyd Davies, however, have established that Merinos are better milkers than has previously been supposed and, even more importantly, that actual milk yields of such ewes tend to be an expression of the suckling activity of the lamb

or lambs. This finding emphasises the significance, to maximum milk yield, of the suckling stimulus and the regular removal of milk from the udder and strongly suggests that the more rapid growth of the heavier and more vigorous lambs from ewes well-fed in late pregnancy can be accounted for to a considerable extent by the higher milk yield of their mothers induced by the lamb's suckling activity.

The use of implants of synthetic oestrogens to stimulate the growth-rate and increase the feed efficiency of lambs has not proved successful under Australian conditions. In the recent experiments of Robinson with "sucker" lambs in New South Wales, growth-rate was significantly improved by such implants but the pattern of development of the animal was profoundly altered and the effects on carcase quality were disastrous. The period of juvenile growth of the lambs was found to be prolonged by the oestrogen treatment at the expense of fattening, i.e. of the late-developing adipose tissues. The disparity between these results and those which have been obtained in U.S.A. reflect basic differences between the lamb industries in the two countries. The lambs treated by Robinson were younger in age and at an earlier stage of development than typical U.S. "feeder" lambs and their diet while grazing, due to its relatively low energy:protein ratio, was also less suited to maximum response from oestrogens.

FERTILITY IN CATTLE AND SHEEP

Infertility in cows is regarded as one of the greatest and most persistent sources of economic loss to the dairying industry, yet few systematic studies of this problem have been undertaken in Australia, other than of brucellosis and its control by means of strain 19 vaccination. The elimination or amelioration of this disease should provide improved opportunities for defining and attacking other causes of bovine infertility, especially the seasonal infertility, apparently of nutritional or metabolic origin, which is of widespread occurrence in Australian dairy herds. By contrast, infertility in sheep has been the subject of numerous investigations concerned with virtually every phase of the reproductive cycle in both ewes and rams.

One of the first workers in this field was Kelley, who placed the time of mating of Merinos on a more factual basis by defining the time and duration of the breeding and non-breeding seasons in ewes under Australian conditions. Using continuous association with vasectomised rams, this worker found that Merino ewes in eastern Australia exhibit maximal incidence of oestrus during late summer and autumn and minimal incidence during the spring and early summer. Underwood and Shier, working in Western Australia, and using the same technique, observed an essentially similar seasonal pattern, although the opening of the breeding season, i.e. the maximum onset of oestrus, was found to be one to two months earlier. The breeding season of crossbred and British breed ewes was shown to open later and to be of shorter duration than Merinos run under the same conditions.

These findings have been confirmed and greatly extended by the more detailed studies of Watson and his associates in Victoria, who demonstrated that not only the oestrus incidence but the overall sexual activity of ewes, including the occurrence of ovulation and twin ovulations, follows a similar seasonal pattern and is influenced by the same changes in the physical environment, namely temperature and length of day, which overseas scientists had shown to influence the occurrence of oestrus. The important practical conclusions to be drawn from these findings are that mating during the peak of the breeding season results in more ewes taking the ram since more are in oestrus, in a greater proportion of conceptions in those that do mate, in a higher ratio of twins to single lambs, and in more ewes carrying their lambs to full term. A statistically significant variation in the ratio of twin to single ovulations, with a peak in autumn and a trough in spring, was also shown by Radford to occur in Merino ewes

when consuming a constant diet. A nutritional influence towards twin ovulations can occur, however, when imposed upon a high level of sexual activity induced by the physical environment. This was strikingly demonstrated by Underwood and Shier with Merino X Border Leicester ewes flushed with a high plane of nutrition prior to mating at the height of the breeding season. The flushed group of ewes produced 18 per cent. twins compared with 2 per cent. in the controls.

Certain discrepancies between the breeding performance of ewes continuously associated with rams, as in the oestrous incidence studies of Kelley and others, and that of ewes joined with rams after a period in which there was no such association, led to the suggestion that the sudden presence of the ram itself could stimulate ovarian activity in ewes. This was convincingly demonstrated by Riches and by Watson, whilst the latter showed further that either the sight, smell or sound of rams is sufficient. These findings have led to the practice of introducing vasectomised or teaser rams to the ewes a fortnight before the fertile rams, thus advancing the time of the peak of conception by two weeks and producing a more concentrated lambing. This effect has been demonstrated only when teasing is employed at the time of the year when reproductive activity in the ewe is normally beginning to increase.

The late commencement of the breeding season in most British breed ewes can be a serious disadvantage to breeders since it necessitates lambing at a time of the year when, in southern Australia, the quantity and quality of the annual pastures are normally declining. Considerable success in inducing oestrus and ovulation, but less success in securing actual lambing, in such ewes during their normal non-breeding season as well as during the breeding season has been achieved by Robinson and by Davies and Dun, by means of suitably spaced injections of progesterone and of pituitary gonadotrophin preparations.

Several workers have observed a seasonal rhythm in sexual activity in rams, with a peak in autumn and a trough in spring, although this pattern is apparently neither as clear nor as general as it is in ewes. The extensive investigations of Gunn, however, have revealed the marked influence of season upon ram fertility, through its effect on the quantity and quality of the semen. This is especially noticeable in the summer in northern Australia, where prolonged periods of high temperature and humidity occur, often accompanied by a low plane of nutrition. Experiments under controlled environmental conditions showed that several weeks of high body temperatures, whether this was due to the climatic environment or to infections or parasites, were sufficient to affect spermatogenesis in rams, resulting in the production of semen low in numbers of normal, active sperms. It was shown, further, that sperm production can be similarly affected by vitamin A deficiency, as was mentioned earlier, and to some extent by other dietary deficiencies, notably of protein.

Mating of a ram producing semen rich in well-formed motile sperms with a ewe in oestrus and ovulating normally is not sufficient to ensure fertilisation, in view of the very short effective life span of the ovum following ovulation and of the sperms once they have entered the female tract. A greatly increased understanding of this phenomenon has emerged from the basic investigations of Austin and Braden. These workers showed that sperms need a maturation or conditioning period of some hours within the female genital tract before they are able to penetrate the membranes surrounding the ovum; that the membranes react to the first sperm passing through them in such a way that the chances of penetration by a second or later sperm are greatly reduced; and that the protective mechanism against several sperms entering an ovum, which could result in abnormal development and embryo mortality, is weakened as fertilisation is delayed after ovulation. These findings have served to emphasise and explain the importance to fertility of the time of mating during oestrus and of the conditions existing within the female genital tract at this time.

SUBTERRANEAN CLOVER AND SHEEP BREEDING PROBLEMS

The most remarkable example of the effect upon fertility of an unfavourable environment in the female reproductive tract is that of the breeding problem in sheep grazing subterranean clover dominant pastures which arose dramatically in Western Australia in the early 1940's. Isolated occurrences were subsequently reported in South Australia and Victoria, but in Western Australia the problem assumed serious proportions and was followed by a widespread and progressive decline in the breeding capacity of ewes, with lambing percentages as low as 10 per cent. and ewe wastage as high as 30 per cent. The disease was manifested clinically by female infertility, maternal dystocia, prolapse of the uterus, and lactation in the unbred female and castrated male, together with various changes in the uro-genital tract of the latter, and pathologically by cystic glandular hyperplasia of the uterus (cystic endometrium) of ewes. The fertility of rams was unaffected by the clover dominant pastures and no breeding abnormalities were observed in cattle or horses grazing such pastures.

Investigations over a period of years by a team of scientists established that the disease is due to the ingestion of excessive quantities of an oestrogenic substance in green subterranean clover, which induces permanent lesions of the uterus and therefore an environment unfavourable to fertilisation or implantation or both and that most of the potency of the clover can be accounted for by the presence of a new type of oestrogenic compound, isolated and identified as the isoflavone, genistein.

Examination of a large number of samples of *T. subterraaneum* revealed that all strains of this species contain genistein in approximately the same high concentrations when green and growing, i.e. prior to wilting, whereas other clover species, grasses, cereals and herbs growing under the same conditions, as well as dry, mature sub-clover, are non-potent. No consistent relationship between potency and soil type or fertiliser treatment was observed, although any environmental factor which promotes clover dominance, or which prolongs the growing period of the clover, enhances the deleterious effects on the animal through increasing the amount of genistein ingested. Finally it was demonstrated that a high degree of control can be achieved in the field by husbandry practices designed to reduce green sub-clover intakes by breeding ewes. These involve particularly, cereal growing under a ley-farming system to help control clover dominance and provide alternative grazing, incorporation of more productive grasses into the pasture and conservation of clover and cereal hay for feeding to ewes during the autumn and early winter. The adoption of these practices by farmers has markedly reduced, but not entirely eliminated the incidence of this disease.

MINERAL DEFICIENCIES AND EXCESSES

The Australian environment has provided many challenging problems in mineral nutrition of grazing stock. The definition and solution of these problems and the development of practical control measures are among the most economically important and scientifically stimulating achievements of Australian science. New and increased understanding of the physiological functions of minerals in the animal body has also emerged; soil-plant-animal interrelationships among minerals have been given added meaning and significance; and naturally-occurring mineral deficiencies or excesses have been shown rarely to occur in simple or uncomplicated form but to be generally ameliorated or accentuated, i.e. conditioned, by the extent to which other minerals or nutrients are present in the diet.

Phosphorous

The known low phosphorus status of most of our soils and the occurrence of annual dry periods when the herbage can be extremely low in this element, together with the world-

wide publicity given to the classical South African investigations demonstrating the value of phosphatic supplements for cattle on veld grazing, led to the widespread practice of providing such supplements to grazing sheep and cattle in Australia. Experiments carried out in the 1930's by Marston and by Underwood and their respective co-workers showed clearly that sheep can fulfil their phosphorus requirements from herbage with much lower phosphorus concentrations than can cattle and that phosphatic licks, even when readily consumed in considerable quantities, confer no discernible benefit on sheep. In fact the latter workers, in an experiment carried on over four successive seasons at Wongan Hills, where the soils are of exceedingly low phosphorus status, observed no effect of phosphatic licks upon the body-weights of ewes, the birth-weight, growth-rates or numbers of lambs born from these ewes, or upon the wool production of mature or growing sheep. They found further, in contrast to the South African findings in respect to the control of "lamsiekte" (botulism) of cattle, that the provision of supplementary phosphate had no influence upon the incidence of the depraved appetite or "pica" which impelled sheep to consume bones and carrion infected with *Clostridium botulinum*.

As might be expected from their higher relative requirements than sheep, evidence of phosphorus deficiency in grazing cattle, especially milking cows, has been obtained from many parts of the continent. In northern Queensland the cattle disease "peg-leg", characterised by poor growth, infertility, lameness and skeletal abnormalities, was shown by Turner and others to be an aphosphorosis, caused by a deficient intake of phosphorus from the herbage, particularly during dry periods, and largely prevented by supplementary phosphate. In Western Australia, extensive studies by Snook have disclosed the fact that phosphorus deficiency is common in dairy herds. This worker has shown that the phosphorus content of the pastures in this area, even when green and growing and treated with the usual dressing of superphosphate, is sufficient only for the requirements of a two-gallon cow, while during the dry, summer period the phosphorus intake is barely adequate for the maintenance of a dry animal. Suggestive evidence was obtained that the provision of phosphatic licks throughout the year, the mixing of supplements such as bonemeal and dicalcic phosphate with the feed in the bails, or the addition of soluble phosphates, including superphosphate, to the drinking water, increase milk and butterfat yields and improve fertility.

Cobalt

Cobalt deficiency in ruminants was first recognised as a result of investigations into "coast disease", which had crippled sheep-raising on the calcareous sandy dunes of South Australia and into "wasting disease" which was seriously hampering the development of dairying in the south-west corner of Western Australia. These maladies of sheep and cattle were characterised, in each case, by loss of appetite, emaciation, progressive anaemia and death. The former was found by Marston and co-workers to be due to a dual deficiency of cobalt and copper in the grazing and to respond to regular dosing with these elements. The latter was shown by Filmer and Underwood to be caused by lack of cobalt in the soils and pastures of the affected area and to be overcome either by oral administration of cobalt alone or by treatment of the pastures with cobalt salts. The application of these findings has enabled large areas in southern Australia and many other countries, hitherto regarded as virtually worthless for stock-raising, to be brought into profitable animal production.

Subsequent studies, especially by the South Australian group, have produced results of great scientific interest and value, linking cobalt deficiency with overseas studies on pernicious anaemia in man and with vitamin B_{12} and disclosing the remarkable fact that ruminants have only an indirect need for cobalt. The real need for this element, it has been shown, is that of the microorganisms of the rumen whose function is to synthesise the needs of the host animal for vitamin B_{12}. Cobalt deficiency in ruminants is therefore

revealed as vitamin B_{12} deficiency and successful prevention or treatment can be secured either by regular and frequent oral administration of cobalt to maintain the capacity of the rumen flora to produce vitamin B_{12}, or by injection of adequate quantities of vitamin B_{12}, thus supplying the tissue needs of the animal for this vitamin and by-passing the rumen. For economic reasons, practical control in the field is usually achieved by treatment of the pastures with cobalt compounds at the rate of 4-5 oz per acre which raises the cobalt level of the herbage above the minimum compatible with normal growth and health (about 0.08ppm Co on dry basis) for two to three years, or, where the soil type precludes this, by regular drenching with cobalt salts not less frequently than once per week at the rate of 7 mg of cobalt per sheep per dose. Recently Dewey, Lee and Marston have devised a new and ingenious treatment —the so-called cobalt bullet, a small dense pellet consisting largely of cobalt oxide. This pellet lodges in the rumen or reticulum and yields, for many months, the small steady supply of cobalt which the rumen organisms require.

Copper and molybdenum

Unequivocal evidence of copper deficiency in grazing stock in this country was first obtained in 1937 when Bennetts and Chapman showed that enzootic ataxia of lambs in Western Australia could be prevented by the administration of copper supplements to the ewe during pregnancy. Later this disease was shown to be associated with sub-normal copper levels in the pastures and the blood and tissues of ewes and their affected lambs and with other signs of copper deficiency, notably anaemia and impaired wool growth and quality. The relation of these conditions to lack of dietary copper was subsequently confirmed and greatly extended by Marston and coworkers in their studies of "coast disease". Since that time copper deficiency in grazing sheep and cattle has been demonstrated over wide areas and in every state of the Commonwealth. The deficiency which, unlike that of cobalt, can also affect crop and pasture growth, has been found to range from mild forms, in which impaired keratinisation and pigmentation of the wool, as mentioned in the section dealing with nutrition and wool growth, are the only signs of lack of copper, to more acute forms expressed in a variety of clinical conditions. These latter include demyelination of the spinal cord which is responsible for ataxia in lambs and is largely confined to ovines; fibrosis of the myocardium or "falling disease", which is restricted to cattle; bone defects, resulting in spontaneous fractures; and gastro-intestinal disturbances (scouring). All of these abnormalities can be prevented or ameliorated by suitable copper supplementation, either through treatment of the pastures with copper ores, by the provision of copper-containing licks or drenches, or, as Sutherland has shown, by intramuscular injections of organic copper complexes.

Basic studies of the biochemical mechanisms underlying the various manifestations of copper deficiency have not, so far, been as successful as the investigations leading to their delineation and control in the field, although Gallagher, an Australian working in London, has shown that copper is basically concerned with the synthesis of heme a the prosthetic group of cytochrome oxidase, the terminal enzyme of cell respiration, and has provided a convincing biochemical explanation of the occurrence of demyelination in the new-born copper-deficient lamb. Far-reaching advances have been made, however, in our understanding of the factors influencing copper adsorption, retention and excretion, and hence of copper requirements by ruminants, as a result of the researches of Dick.

These findings emerged from the investigations of chronic copper poisoning in sheep which was shown by Bull and Dick to occur in eastern Australia under three different sets of condition. These are (1) where the copper content of the soils and pastures are abnormally high, leading to "straight" copper poisoning, (2) where these are normal but the molybdenum levels are extremely low, giving a high Cu:Mo ratio and leading to "conditioned" copper poisoning, and (3) where

liver damage due to poisoning by the plant *Heliotropum europaeum* occurs. The provision of molybdate supplements was found by these workers to reduce the amount of copper retained by the animals and hence the incidence of copper poisoning. In a brilliant series of experiments. Dick went on to show that the inhibiting effect of molybdenum on copper storage is exerted only in the presence of adequate dietary intakes of inorganic sulphate. The absorption, excretion, and route of excretion, of molybdenum was also shown to be profoundly influenced by the level of dietary inorganic sulphate. Much remains to be learned of the quantitative dietary relationships among copper, molybdenum and sulphate and of the physiological mechanisms involved, but it is clear that the conditions determining the occurrence of copper and molybdenum deficiencies and toxicities in animals are extremely complex. They are influenced not only by the levels of copper, molybdenum and inorganic sulphate in the diet but by the intakes of protein and manganese and by the previous history of the animals in respect to intakes of these nutrients.

An important conclusion which can be drawn from these findings is that estimates of minimum copper requirements based solely on copper intakes can be very misleading. In fact it follows that there must be a series of copper requirements depending upon the extent to which the various factors affecting copper metabolism are present or absent from the diet. As Dick has pointed out, a "true" or basic copper requirement must now be conceived as one in which all the dietary conditions affecting copper are at an optimum. A comparison of Dick's estimates of minimum requirements with those obtained in the field suggest that such optimum conditions do not occur widely in Australia. Furthermore, important field differences have been revealed in the minimum intakes of copper compatible with complete freedom from any signs of copper deficiency which illustrate the impact of dietary factors other than copper on copper requirements. Thus Beck has shown 6ppm Cu on the dry basis to be entirely adequate for grazing Merino sheep under Western field conditions, whereas Marston and co-workers claim that close to 10ppm is necessary for similar animals under the conditions pertaining on the calcareous littoral of South Australia.

MILKING PERFORMANCE OF COWS

A vast amount of work of an applied nature has been carried out by State Departments of Agriculture with the overall objective of increasing milk yield and quality and of raising the technical and economic efficiency of dairy farming. The best times of calving have been established for a range of environments; calf-rearing techniques and bail-feeding procedures, which utilise local feeds to the best advantage, have been devised; non-stripping of cows has been shown to save time and labour with no significant loss in production or persistency of lactation; various mineral deficiencies, especially of phosphorus, cobalt and copper, have been delineated and practical control measures proposed; and a great deal of valuable data has been accumulated on the best grazing management and fodder conservation practices for particular districts. In addition major measures, such as herd-recording and artificial insemination schemes, have been fostered and developed.

Although these developments have had considerable impact upon dairy husbandry practices, they have mostly been applications of overseas research findings and have had little support from basic investigations in this country designed to increase our understanding of the physiological mechanisms involved. An exception is provided by the work of Turner on the factors determining the amount of residual milk in dairy cows and the influence of varying milking intervals on total daily milk yield. In a series of critical studies, Turner showed that the amount of residual milk averages about 20-30 per cent. of the total milk, although the proportion varies markedly and characteristically with different cows. It was found, further, that not only is the proportion of residual milk a strongly inherited character but it is inversely related to persistency of lactation, i.e. cows with

higher proportions of residual milk tend to have shorter lactations. Inherent speed of milking, which in turn is influenced by the size of the teat opening, is believed by Turner to be one of the causes of differences in residual milk.

Studies of varying intervals between milkings revealed that intervals even as unequal as 8 hours (day) and 16 hours (night) do not lower total production compared with equal intervals of 12 hours. The well-known fact that milking after the longer night interval produces relatively less milk and fat than the afternoon milking was thought to be due to a lower secretion rate at night because of excessive filling of the udder and the development of high mammary pressure. Turner's investigations have shown that secretion rate is not lower at night and that the milk secreted by day and by night is fairly constant in fat content. The discrepancy between day and night yields was found to arise from differing completeness of removal of milk from the udder at day and night milkings. A similar mechanism was shown to influence fat yields, the effect being greater because of the high fat content of residual milk.

PIG AND POULTRY NUTRITION AND MANAGEMENT

Numerous investigations of a practical nature aimed at improved pig and poultry husbandry have been carried out by all State Departments of Agriculture during the last 25 years. Particular attention has been paid to such factors as early weaning, deep litter rearing, the place of dietary antibiotic, vitamin and mineral supplements, and the best and most economic proportions of skim-milk, protein concentrates, green fodders and grazing that can be included in the feeding and management regimes, but very few basic physiological studies have been conducted with either species.

The dependence of Australian pig and poultry production upon cereal grains, especially wheat, and upon meat meal as a protein supplement has stimulated investigations of their nutritive value. Underwood and coworkers showed that Australian grown wheat and oats normally supply sufficient manganese for the requirements of poultry, whereas diets based on maize or barley are likely to require supplementation with this mineral. Indications that zinc deficiency (parakeratosis) can be of considerable economic importance in pigs fed rations of cereal grains, meatmeal and calcium supplements have been obtained by Wilkie and Bussell. It appears that the condition, which responds readily to zinc supplementation of the ration, is due more to a relative excess of calcium than to low levels of dietary zinc.

The nutritive value of Australian meatmeals has been studied by Underwood, McClymont, McDonald, Morrison and others. These studies have revealed marked variation in protein content and in the digestibility and biological value of this protein. It is now apparent that many of them are greatly inferior in promoting chick growth to such overseas protein sources as fishmeal, whalemeal and soyabean meal and that this inferiority is due partly to their low content of B vitamins other than riboflavin, partly to a deficiency of certain essential amino-acids, particularly methionine, and partly to the presence of a toxic factor or factors. The toxic factor has not yet been identified but McDonald and Beilharz have found that it is confined to low protein meat and bone meals (42 per cent. or less), is located in the ash of the bone fraction of the meal, and is highly toxic to chickens but harmless to adult laying hens.

The importance of methionine for the growth of chicks fed diets based on wheat products and meatmeal was established by McDonald. This worker found that the growth rate of White Leghorn chickens on such diets was increased by additions of up to 0.2 per cent. DL-methionine, whereas Australorp chickens did not show this response, because of their inherited inability to synthesise cysteine from dietary methionine. White Leghorn X Australorp cockerels and their reciprocal crosses, on the other hand, showed a significant response in weight gains and in feed efficiency over a 12 week period when given a 0.1 per cent. methionine supplement to a high-

energy commercial-type diet. When a low-energy diet of this type was fed, the methionine supplement produced a highly significant improvement in feed efficiency but not in weight gains. The importance of these findings and this type of investigation to an efficient broiler industry in this country needs no emphasis.

GENERAL CONCLUSION

Although the record of Australian achievements in animal production research outlined above is one of which any country might well be proud, it is not without some disquieting features. The most obvious of these is the overwhelming emphasis on sheep and wool problems, coupled with a neglect of pig, poultry and dairy production research, especially in its more basic aspects. Whilst it could be argued that this is justified in view of the much greater economic importance of sheep and wool to Australia, it should be appreciated that the individual meat, milk and egg producer has technical problems just as serious and as vital to his welfare as does the individual wool-grower. Moreover, fundamental research not only provides the essential background to effective applied research, it has also the habit of upsetting beliefs and practices cherished by custom and hallowed by time. It is upon challenging developments of this nature that real progress ultimately depends. The advent of the new industry funds from the beef and dairy levies is an encouraging sign. It is hoped that they will foster basic research, as has been done so successfully in recent years by the wool research funds.

An even more disquieting feature is the fact that, although the major Australian animal industries have grown greatly in size over the last 25 years, there has been disappointingly little improvement in productivity per animal, except with the wool sheep. In the light of the wealth of new technical knowledge obtained, the conclusion is inescapable that many farmers and graziers are either unaware of its existence or they are unable or unwilling to take advantage of it. Such a conclusion suggests the need for a critical examination of the whole process by which research findings are applied, or not applied, in the field, and for an equally critical examination of applied research itself to determine how far it is orientated towards the real needs of the practising farmer and grazier.

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PLANT IMPROVEMENT

R. D. BROCK and
O. H. FRANKEL

The scientist turning amateur historian finds himself faced with an unfamiliar task. He is accustomed to deal with the future rather than with the past; to expose ideas to experimental tests rather than to the bias of his own attitudes. In this predicament we turn for comfort to the familiar world of scientific exposition and first define our material and modes of procedure.

In the first instance, we outline what we regard as the more significant developments in plant improvement. Next we deal with breeding progress in a range of crops, attempting to include some typical projects in addition to major achievements, and, as far as possible, current work embodying new and significant approaches. We shall examine these endeavours in the light of existing basic knowledge on the one hand, the requirements of Australian agriculture on the other, thus pointing not only to strength and weakness, but to leads and needs for future developments.

We are indebted to many colleagues for supplying information on unpublished and current work. Even though a good deal of this could not be included, it all helped to provide a background.

GENERAL

Objects and objectives

Breeding work on the main field and horticultural crop plants was continued. A major development during the period under review is the intensification of breeding—and introduction—of pasture plants.

The principal objective in pasture plant improvement in Australia is to extend pasture production in time and in space: in time, to even out production troughs; in space, since occupation of ever further regions demands plants adjusted to ever more difficult environments. Research in pasture ecology and utilization has helped to clarify the objectives and thus to provide criteria for discrimination; indeed, it is this advancing knowledge which has created both the need and the condition for plant improvement. Yet, how woefully inadequate it is even now as an aid to selection, especially at the plant breeder's level of single plant or small plot!

Turning to the crop in which Australian plant breeding has scored its greatest successes, wheat, changes in emphasis have been caused less by scientific developments than by trade demand. Pressure for higher baking quality

for home consumption dates back to the early decades of the century: the marked improvement in quality in some varieties produced in the period under review, with Gabo in the lead, has been the result. The emphasis on "quality" in the export trade is a recent and still contentious development. Yet, in spite of repeated requests, wheat breeders have not succeeded so far in obtaining clear directives on desirable grain properties which would serve as breeding objectives. The reasons are perhaps twofold: an insufficient clarity on market requirements, and an insufficient knowledge of the scientific bases which would facilitate quality specifications.

These examples illustrate the plant breeder's growing dependence on others for help in defining breeding objectives—an inevitable consequence of the increasing complexity in the productive, manufacturing and marketing processes. The plant breeder's yardstick is no longer yield alone; economy or ease of production, advantages in manufacturing, transport or marketing have acquired equal, and often dominating, prominence.

Range of variation

Since all the plants of developed agriculture in Australia are introduced, plant improvement in the first instance depends on plant introduction. In the last twenty-five years the three phases of plant introduction—acquisition, examination and application—have been intensified and systematized. The period under review saw the first Australian plant exploration expeditions in regions of great interest to Australia—in most of the Mediterranean countries, the southern half of Africa, Central America, Brazil and Chile. Much valuable material and experience were acquired.

The period saw the establishment of plant introduction stations in various regions of the Commonwealth, where new material receives its first examination for potential usefulness under Australian conditions.

The weakest link has been the exploitation of introductions. No introduction, promising though it may be, will get beyond the test plot unless it is adopted and, if need be, adapted by agronomist, horticulturist or plant breeder; and this, so far, has proved a lengthy and uncertain process. In the United States, where the number of introductions is many times that in Australia, the ratio of those used directly or in plant breeding projects is 1 in 250—many times higher than in Australia.

Yet the period under review has seen several successful introductions—the Gayndah and Biloela strains of buffel grass, *Sorghum alum,* Currie and Neptune cocksfoots, Beecher barley, annual grain legumes, Walsh linseed, many horticultural varieties, and others. Many, yet all too few, new introductions have been, or are being, used by plant breeders.

Plant breeders have taken advantage of the greatly expanded range of variation which has become available, especially in pasture plants. In many crops, plant breeders have taken a new look at the nature and range of variation they are using. Two examples may suffice. In phalaris, the aim is to expand the habitat range beyond that of the adapted species, *Phalaris tuberosa,* hence variation was expanded by interspecific crosses. Use was made of diverse types within the parent species to increase the range of variation in the evolving alloploids.

By comparison, in wheat, a crop which has been the object of extensive plant breeding activities, there is a tendency to narrow down the range of variation to that which is provided by inter-crossing of well adapted types, as one of us pointed out some years ago[1]. For many years infusion of new germ plasm has been confined to resistance genes, incorporating a minimum of the "foreign" genotype. Recently, the Waite Agricultural Research Institute and the Victorian Department of Agriculture have embarked on projects in which a large range of introductions are being tested for their "combining ability" with adapted Australian types. These experi-

1 Frankel, O. H. (1954)—*Caryologia,* Suppl. to vol. 6: 600-619.

ments must be followed with a good deal of interest since the lesson they hold may apply in other plants.

Another direction in which the range of variation is to be expanded is the utilization of induced mutation in plant breeding. Work along these lines has commenced in several centres, and the C.S.I.R.O. Division of Plant Industry has established a unit for the study of induced mutation which is being equipped with suitable radiation sources.

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Biological intelligence in plant breeding

To extend the range of variation is one component in the advancement of plant improvement; to render this range ever more meaningful in terms of the environment to be served and the plant characters to be adapted, is the other. For the state of our knowledge will affect the significance of the choice of parental material, and of the method and direction of selection and testing. This is no new concept for plant breeders. Plant pathologists for many years have made all-important contributions to resistance breeding through the study of the genetics and physiology of host-pathogen relationships on the one hand, heredity-environmental interactions in disease incidence on the other; and during the last twenty-five years, the distinguished Waterhouse-Watson group at Sydney University has added further to our thinking and to our knowledge on disease resistance. In the field of less "observable" characteristics, which as a rule are controlled by more complex gene systems, progress is more recent, yet of distinct promise. We confine ourselves to a few significant approaches, and first discuss physiological and biochemical studies of plant characteristics of relevance in plant improvement.

The determination of flowering time in subterranean clover has been the subject of many studies. Aitken and Drake first demonstrated vernalization requirements, and observed the effect of photoperiod. Then followed the demonstration of variety x location interactions by Morley and Davern, with an examination of the processes involved. Evans and Morley demonstrated an additional component, requirements for high temperatures, in this and other species. Also in subterranean clover, both Millikan and Morley found variety x temperature interactions affecting productivity. The strains Clare and Wenigup are adapted to higher temperatures than are Yarloop and Tallarook. Clare also has a low vernalization requirement. It therefore should be suited to warmer regions, which in fact it has proved to be. The role of embyro dormancy in adaptation to climate was studied in material from the Mediterranean region and the importance of high levels of dormancy in cool, dry climates has emerged. Black has demonstrated the importance of seed size, and both Donald and Rossiter the importance of seed yield for the establishment and maintenance of subterranean clover swards. In lucerne, we know from work by Daday and Morley that some varieties have greater heat tolerance, others lesser winter dormancy. But all this is only a beginning. We must gain a great deal of detailed knowledge of growth rhythms in production and reproduction so as to tailor our plants more effectively to our environments and our, and our animals', requirements.

Some of the studies to which we have referred were conducted in the field, others under limited environmental control. Much help will come from the great range and precise control which will become available in the Canberra phytotron two years hence. It will depend on the imagination and versatility of plant breeder and physiologist how far these new tools will be put to good use in

plant improvement. Some leads have already been mentioned; other are beginning to emerge. It seems likely, for example, that the physiology of temperature response at low (near freezing point) and at high levels (above 100°F) may provide critical evidence of use to plant breeders.

To resolve complex characters so as to make them amenable to significant and unambiguous tests is a plant breeder's dream. Biochemical research may bring us nearer to this goal in resolving some of our "quality" problems. Workers at the Waite Agricultural Research Institute have begun a concerted attack on the nature of protein quality in wheat, in the first instance by means of an examination of the relationships between amino-acid composition and quality characteristics. As results become available, they are to be utilized in genetic analyses and breeding projects. Similar studies are in progress in barley.

Let us now turn to new approaches in the genetic sphere which have emerged into practical application in several institutions. When dealing with polygenic systems the techniques which are of value for the transfer of single genes, such as back-crossing, are of little use. Griffing[2] has proposed a system whereby the breeder generates variability in the form of a breeding population and gradually moulds this population to suit his requirements. Such a programme requires the critical choice of initial parents, for these set limits to the total variability. Progeny testing, using orthogonal genetic designs and statistical techniques, is utilized in parent selection.

The elite parents are used to generate a dynamic gene pool which is continuously modified by selection, and from which new varieties can be extracted in successive waves. The continuous modification of the gene pool is achieved by first identifying those genotypes with the greatest breeding merit for which progeny testing is again used; and then mixing the germ plasm of these elite genotypes in a recombination block. Such a breeding system maintains genetic variability, increases the frequency of desirable genes and allows tight linkages to be broken.

A gene pool such as this can be maintained as an "open" system into which new parental material can be introduced, thereby taking advantage of new variation as it becomes available, and from which, in turn, new selection lines can be established whenever there is a need for a change in breeding objectives.

Thus while in various ways our knowledge of the plant's life processes, and of the ways these might be adjusted, is growing, our knowledge of the environment to which it is to be adapted is also growing in breadth and in specificity. In the period under review we have increasingly come to appreciate, and to classify, the climatic and edaphic characters of Australian environment. The pioneering work of Christian and his colleagues in the C.S.I.R.O. Division of Land Research and Regional Survey has begun to integrate these classifications in terms of land use systems. When taken to its logical conclusions, this approach should lead to specifications of the plant characteristics required, and of the habitat range of new plants.

With our growing knowledge of the environment and of plant adaptation, the question of the range of adaptation—whether adaptability over a wide range, or adaptation to a narrow one—will become increasingly relevant for plant breeders. This problem has been recently discussed by one of us[3], and is being studied by Finlay and his colleagues with barley.

In this section we have pointed to some leads which biological intelligence is beginning to provide for practical plant improvement in the coming years. We should not like to conclude it without mentioning a pointer in the opposite direction. To this day, and for most crops perhaps as long as plants are raised in the field, every breeding programme has a component of natural selection; but rarely is it used as the only, or principal, selective agent. This is the case in a project in which hybrid populations of subterranean clover are exposed to long-term natural selection in a range of environments

2 Griffing, J. B. (1956)—Conference of Cereal Breeders and Geneticists, C.S.I.R.O., pp. 45a-i.

3 Frankel, O. H. (1959)—*Aust. J. of Sci.* **22**: 27-32.

beyond the habitat of the species[4]. Morley studies the parents and the progress of selection, and will examine the population structure in the various sites on conclusion of the experiments. It should then be possible to test the deductions thus derived in nature, in controlled experiments in the phytotron.

Research and education

There have been striking developments in many phases of research and education relating to plant improvement. In State Departments of Agriculture, which bear the main responsibility for plant breeding activities, there has been a strong tendency towards crop specialization. Where twenty-five years ago an officer may have had half a dozen or even more species in his charge, to-day he specializes on one or a few related species. This has facilitated a greater familiarity with specialized crop and breeding techniques.

A significant development has been the establishment of research teams in genetics and plant breeding in Canberra and Adelaide. Both conduct basic research in plant breeding, though with different emphasis. The Canberra team is concerned with plant breeding methods in the wider sense. This includes work on the physiological and biochemical genetics of mutants, studies in population genetics and selection methods, physiological genetics in crop plants, mutations in crop plants and in *Rhizobium*. The Adelaide team follows similar interests, though it concentrates more particularly on studies of characters of importance in breeding programmes. Both teams have the advantage of close proximity to workers in associated fields of research.

Under-graduate training in genetics is now provided by specialists in all Australian universities. Specialist research departments in genetics have been established in the University of Adelaide, and, through C.S.I.R.O. co-operation, in the University of Sydney; but research and post-graduate training in various fields of genetics takes place in all universities. Perhaps the greatest handicap is the small number of post-graduate students in genetics, which reflects the all too small number of openings in plant breeding.

As a consequence of the intensification of research activities, there has been a marked strengthening of scientific contacts. No longer are plant breeders isolated from each other and from scientists in other fields. Plant breeders' conferences—commenced as Cereal Breeders' Conferences in 1946—provide opportunities for exchange of information and ideas, as does the *Australian Plant Breeding and Genetics Newsletter* issued since 1952. Two plant breeding workshops, of several weeks' duration, were held in Canberra in recent years. They dealt principally with breeding and selection methods. The newly formed Genetics and Plant Physiology Societies are beginning to attract plant breeders. Above all, there have grown up personal contacts, within and between states, among workers in departments, universities and C.S.I.R.O.

SPECIFIC

Wheat

Of all the economic plants in Australia, wheat alone owes its prominence, in fact very nearly its existence, to the plant breeder. No other crop bears less of the mark of its origin, or more of its adopted homeland. This dependence has continued during the period under review and to-day wheat depends on the breeder for defence against disease, and perhaps soon for its place in overseas markets.

There have been recent reviews of wheat improvement during our period[5]. Here we can only review some salient features.

The varietal composition changed greatly during the period. It saw the rise and decline

4 Morley, F. H. W. and Frankel, O. H. (1959)—in "Biogeography and Ecology in Australia". Monographiae biologicae **8**: 577-586.

5 e.g. Macindoe, S. L. (1952)—*World Crops, vol.* **8**. Crop Pasture and Fruit Breeding in N.S.W., Science Bull. 72, N.S.W. Dept. of Agric.
Callaghan, A. R. and Millington, A. J. (1956)—"The Wheat Industry in Australia". Sydney.

of Bencubbin throughout the main wheat states, and since 1950 a similar rise of Gabo. Victoria saw the decline of Ghurka, the rise and fall of Quadrat, the recent rise of Insignia and Pinnacle. There is no doubt that yield was the driving force, combined with disease resistance; nor that substantial yield increases have been achieved. New South Wales made the biggest contribution to quality improvement with Gabo, which, until ten years ago, possessed rust resistance; but Warigo, a South Australian wheat with low quality but resistance to stem rust, is now spreading in New South Wales. South Australian, and to some extent Victorian, varieties have shown a steady improvement.

Bird, at the Wagga Agricultural Research Institute, demonstrated the dangers of some widely used methods of quality assessment in failing to uncover starch weaknesses. The Victorian Department of Agriculture is making a concerted drive for a genetic improvement of nitrogen content; and all Departments continue their efforts to improve overall baking quality. Help is likely to come from research in departmental laboratories and the Bread Research Institute, and from the research groups established recently in Sydney, Melbourne and Adelaide under the auspices of the Wheat Industry Research Fund.

However, yield has remained the central theme, and the recent attempts to seek improvement through infusion of new blood have already been mentioned. One of the largest sources of loss in New South Wales is frost damage, and resistance or escape has been obtained in crosses with winter wheats.

The most notable achievement in wheat improvement, and one of the most notable in plant improvement in general, has been in the field of resistance to major diseases —bunt, flag smut, leaf rust and stem rust. An excellent review of this work has recently been compiled by Watson[6].

Pugsley identified five races of bunt in Australia and found sources of resistance to all of them. In a remarkable breeding programme, using the backcross method which he popularized in Australia, he incorporated successively resistance to all strains in several standard varieties. Unfortunately resistance breaks down owing to recombination, and the adaptive capacity of the parasite has kept pace with breeding for resistance. So far, however, a combination of resistance and dusting has kept the fungus under control.

The flag smut fungus, on the other hand, has a lesser adaptive potential. Some of Farrer's varieties possessed resistance which has been incorporated in all modern wheats. Watson suggests that restricted variability in the fungus and complex inheritance of the resistance mechanism are responsible for the stability of the resistance system.

The interactions between the leaf rust organism and the wheat plant are more complex than either of these, with new races arising not infrequently through mutation, recombination or both. There are two sources of resistance available in Mentana and Uruguay which Watson and his associates have used; but a new source, from *Aegilops umbellulata,* confers resistance to all local strains. This, combined with older sources, should give powerful protection.

In the little space available, it is simply impossible even to attempt a review of the achievements, or even of the significance, of the work on stem rust by the Sydney University group, first under Waterhouse, more recently under Watson. Surveys of rust races in Australia and New Zealand over many years, reactions on a great range of varieties and hybrids, inheritance studies of various sources of resistance have made it possible to arrive at generalizations on the biology and epidemiology of the rust-wheat system which hold lessons far beyond even this awe-inspiring parasite. It may be disappointing that the dogged work of combining various types of resistance stands at the end of these studies; but this defence is as good as any known to man against the adaptive cunning of our enemies.

6 Watson, I. A. (1958)—*Agric. Gaz. N.S.W.* **69**: 630-60.

Maize

Australian work on the development of hybrid combinations has followed the pattern set in the United States. Inbreeding and selection was initiated in Queensland and New South Wales at an early date. More recently, the Shand Selected Seed Company has been supplying hybrids based upon American inbred lines. Queensland tests demonstrated that from more than 1,000 local and introduced inbreds, the most useful have come from varieties established in Australia for many years. Local hybrids are now available for all areas in Queensland except the Atherton Tableland. In New South Wales late maturing hybrids, resistant to Helminthosporium blight and weevils, suitable for the north and central coastal areas, and short season hybrids suitable for tableland, south coast and inland areas have been developed.

Good progress is being made towards the introduction of male sterility into all these programmes as an aid to the cheaper production of hybrid seed. Hybrid popcorn and hybrid sweet corn have now displaced open pollinated types and a waxy hybrid, which will provide starch with special properties valuable in industry, will be available for release in 1961.

Tobacco

The Australian tobacco crop has always been grown from introduced varieties or local selections from these varieties. Marked yield and quality improvements have resulted from the more recent introduction of Virginia Gold and Hicks. However, these varieties are susceptible to blue mould. Vigorous efforts to develop blue mould resistance have been made by the N.S.W. Department of Agriculture and the C.S.I.R.O. Division of Plant Industry. Among the resistant endemic species, *Nicotiana debneyi* has been hybridized with commercial *N. tabaccum*. Continued back crossing to fertile alloploids has resulted in the incorporation of resistance into lines which are now being tested for their suitability as commercial varieties. The N.S.W. Department of Agriculture expects to release a resistant variety shortly and a promising line has been produced by C.S.I.R.O. in Canberra. Efforts to induce resistant mutants are also in progress.

Oil crops

Safflower has been established as a crop for drier areas. A variety, adapted for use in Queensland and northern New South Wales, was produced by, and named after, the late Dr. Horowitz who was largely responsible for the establishment and development of this crop in Australia.

A high yielding, disease resistant variety of linseed, Hazeldean, was developed by the Victorian Department of Agriculture. Breeding has been continued and further improved varieties are on the way. The variety Bonnydoon is being released this year.

Sugar cane

Both the Colonial Sugar Refining Company and the Queensland Bureau of Sugar Experiment Stations have been active in the production of improved sugar canes. The Bureau of Sugar Experiment Stations was reorganized in 1949, and considerable attention is now devoted to breeding as well as to research into breeding methods and genetical studies on quantitative inheritance.

New varieties have resulted in a notable increase in yield of sugar by increasing the sugar producing capacity of the canes as well as by the incorporation of disease resistance. Over the last twenty-five years the proportion of the Australian crop grown from locally produced varieties has risen from 23 per cent. to over 80 per cent. Recently more attention has been given to developing varieties for specific areas, with special attention to characters such as resistance to lodging and drought, and suitability for mechanical harvesting. Collecting expeditions to New Guinea in 1951 and 1957 supplemented the already extensive gene pool available to the breeder.

Sugar cane is an outstanding example of the successful use of interspecific hybridization. The disease susceptible noble canes (*Saccharum officinarum*) have now been replaced by interspecific hybrids involving *S. officinarum, S. spontaneum, S. sinense and S. robustum.*

The increased yield and the disappearance of previously important problems such as gummosis, downy mildew, and Fiji disease, mark this as one of the most successful examples of plant improvement during the period.

Vegetables

Introductions and farmers' selections from older varieties make up the bulk of the vegetable varieties now in use in Australia; but research has contributed notably to disease resistance and to the production of new varieties in a number of crops.

Hutton contributed valuable sources of resistance to virus in potatoes. His work, based upon the development of resistance within intraspecific crosses, contrasts with that largely in use overseas which is based upon the transfer of resistance from other *Solanum* species. The failure of interspecific hybrids of *Solanum* to contribute to general improvement of potatoes contrasts sharply with the success of interspecific hybridization in sugar cane.

Breeding for resistance to a number of diseases of potatoes is being conducted by the Departments of Agriculture in Victoria, Tasmania and New South Wales and varieties resistant to early and late blight have been produced in New South Wales. Five varieties produced in New South Wales are being extensively grown on the Southern Tablelands but despite this, more than sixty per cent. of the New South Wales crop is produced with varieties introduced from the United States of America. The marked yield increase in Victoria is also attributed to the use of introduced varieties and the control of virus disease.

Tomato varieties resistant to fusarium wilt and root-knot nematode (*Meloidogyne javanica)* were produced at the Commonwealth Research Station at Merbein. Subsequently a strain of nematode capable of breaking down this resistance was found. Efforts are now being made to induce mutants with resistance to this more virulent strain.

Surveys of the strains of tomato spotted wilt virus present in Australia were made by Norris and by Finlay and some sources of resistance were located, but no resistant varieties have been developed. Recently Nirk showed that reciprocal grafting enhances crossing between *Lycopersicon esculentum* and *L. peruvianum.* This discovery could facilitate transfer of disease resistant genes from *L. peruvianum.*

Shirlow produced several improved varieties of French beans, but Brown Beauty has not been replaced as the premier variety in Australia. It has long been known that variability existed in Brown Beauty and the late Dr. Wilson selected an anthracnose resistant strain which is being widely grown. Pure lines selected from Brown Beauty have been tested for yielding ability against mixtures in Queensland. The results confirm those of Suneson and others in California in showing that mixtures of pure lines tend to give better yields than any of the individual lines. Rust resistance has been incorporated in the pole bean, Westralia, by Cass-Smith, Harvey and Goss and in a French bean in Queensland.

Testing of inbreds for the production of hybrid seed is in progress with onions in Victoria and with tomatoes at several centres.

Fruit

Most fruit varieties in use are of considerable age and scientific plant improvement has not contributed materially to their production.

Introduced rootstocks for apples and pears are being tested for resistance to disease and pests and for their influence upon scion characters. Some locally selected stocks, Northern Spy No. 6 for apples and *Pyrus calleryana* D-6 seedlings for pears, are now in commercial use.

Breeding for resistance to black spot in apples has been initiated in both New South

Wales and Victoria but no resistant material has so far been released. In Tasmania, however, red bud sports of Jonathan and Delicious have been selected and are being extensively used in areas where good colour is difficult to obtain.

Bud selection work in citrus has resulted in a notable improvement in the quality of the fruit and a reduction in the incidence of disease. This work was initiated by the recognition of the importance of Phytophtora root rot during the late 1930's and the subsequent use of *Poncirus trifoliata* as a resistant rootstock. This rootstock revealed the widespread presence of a virus disease or complex of diseases, scaly butt, which is symptomless in the older rootstocks but which reveals its presence on trifoliata stocks. This recognition of scaly butt led to the location, registration and widespread use of specially selected, virus free trees for the supply of buds. The careful selection of trees has resulted not only in a decrease in the incidence of the disease but a general improvement in the quality of the fruit.

In the stone fruits, variability in introductions, open pollinated seedlings, and cross pollinated hybrids has been examined by the Departments of Agriculture in both Victoria and New South Wales. New varieties of canning peaches, dessert peaches, and cherries have been released in New South Wales and a number of new canning peaches will shortly be released in Victoria.

The banana and the pineapple, which are our most important tropical fruits, have received scant attention from the plant breeders. Early work on the testing of local and introduced types has scarcely been added to over the last twenty-five years. Pawpaws have, however, received attention. Early work by Agnew and Summerville has resulted in the development and use of improved commercial types and efforts are now being made to develop inbred lines for the production of hybrids for commercial use.

The possible utilization of induced mutations would seem to have considerable potential in fruit trees and a number of improvement programmes based on the induction of mutations are in progress overseas. However, apart from work which has been initiated at the Commonwealth Research Station at Merbein which is aimed at selecting for root knot nematode resistance and general characters in vines, no other mutation programme with fruit is in progress in Australia.

Pastures

The early part of the period under review is characterized by a general recognition of variability in the important pasture species, and efforts to select better strains of the major species were being pursued vigorously by 1935. These early efforts were followed by the introduction of seed certification for pasture species, first in Victoria in 1935, and later by other states. Breeding was commenced with a large number of the temperate legumes and grasses by the Departments of Agriculture and by C.S.I.R., but this work was disrupted by the war and was never really resumed. In the late 1940's and throughout the 1950's, breeding of a number of temperate and subtropical grasses and legumes was started afresh.

Throughout the whole of the period, important achievements have resulted from introductions. These introductions have, by extensive regional testing, resulted in important commercial strains of several species, and through their incorporation into breeding programmes they are providing a valuable source of genes for future improvement work.

Temperate legumes

Subterranean Clover—By 1935 different strains of subterranean clover were clearly recognized, as was the importance of flowering time for survival. The genetical, physiological and ecological studies discussed earlier have contributed to a greater understanding and use of introductions and to more specific breeding objectives. Plant breeding projects are in progress at the Institute of Agriculture in Western Australia and at the C.S.I.R.O. Division of Plant Industry at Canberra.

At the Institute of Agriculture, Millington has selected the Geraldton strain[7], which is now available for commercial use, and two other very early flowering strains, Carnamah and Neuchatel, from locally acclimatized material, and also several early flowering lines with exceptionally heavy seed yields from his hybridization programme. His students have made genetical studies of the fertility of hybrids, the inheritance of various morphological and physiological characters, and the ecology of seed production.

The work in progress at Canberra integrates plant improvement with genetical and physiological studies. Information on genetic compatibility, flowering time, seed dormancy and temperature response has been related to the ecology of the natural habitat and this in turn has provided information on the areas in Australia where the various genotypes are potentially valuable. These results, together with studies on virus resistance, are being used in a plant breeding programme and a large number of hybrids with improved winter growth are being tested. One of these which incorporates resistance to the subterranean clover stunt virus is being tested by Departments of Agriculture as a potential replacement for the mid-season variety Bacchus Marsh.

The N.S.W. Department of Agriculture has this year released for commercial use a farmers' selection, called Marrah, which shows promise of being superior to Bacchus Marsh in certain localities.

Lucerne—Early work at several localities was aimed at producing better strains of lucerne, but none of those selected were ever shown to be superior to Hunter River which is still virtually the only variety in commercial use in Australia.

Recently, genetical and plant improvement work has been commenced at the C.S.I.R.O. Division of Plant Industry. The introduced variety Hairy Peruvian, and possibly also du Puits, have been shown to be superior to Hunter River at some localities and breeding work is in progress to incorporate higher summer and winter production into locally adapted types. The inheritance of quantitative characters and the possible utilization of heterosis for summer forage production are being studied, and an electrical conductivity test has been developed by Daday and Greenham as an aid to the selection of cold-hardy material.

Efforts are also being made both in Canberra and at the C.S.I.R.O. Division of Tropical Pastures in Gatton, to transfer the creeping-rooted habit, which confers the ability to grow readily on shallow soils and to withstand heavy grazing, from the winter dormant, low yielding Canadian material to locally adapted types.

Annual Medics—Pre-war selection of annual *Medicago* species at the C.S.I.R.O. Division of Plant Industry from locally adapted material has resulted in the recent release of an improved strain of Barrel Medic *(M. tribuloides)* by the N.S.W. Department of Agriculture for use in the north and central west of New South Wales. Testing and selection of species, as well as breeding, is in progress in Victoria, and recently *Medicago littoralis* was released, and named Harbinger, for use in the central and northern Mallee areas.

Tropical and subtropical legumes

There have been continuing and recently intensified efforts to develop pasture legumes for the tropics and subtropics, initially by the New South Wales and Queensland Departments of Agriculture and more recently by the C.S.I.R.O. Divisions of Plant Industry and Tropical Pastures. Several introductions have been naturalized and *Stylosanthes sundaica* which was developed by the Queensland Department of Agriculture is being increasingly used.

Recent intensification of introduction and testing of species and strains has resulted in a wide range of plants showing promise. No less than thirteen genera are represented, the most promising species coming from *Cajanus, Centrosema, Crotolaria, Desmodium, Dolichos, Glycine, Indigofera, Psoralea, Leucaena, Lotononis* and *Stylosanthes.*

7 Millington, A. J. (1956)—*J. Aust. Inst. Agric. Sci.* **22**: 111-119.

Both breeding and screening for desirable mutations are in progress with *Phaseolus atropurpureus, Lotononis bainesii, Indigofera spicata* (formerly *endecaphylla),* lucerne, white clover and *Leucaena glauca.* Two of the most promising species, *Indigofera spicata* and *Leucaena glauca,* contain toxic substances and efforts are being made to reduce or eliminate the toxins.

Temperate grasses

Rye Grasses—Some of the earliest pasture grass improvement work was done in Victoria with Wimmera and perennial rye grasses and during the 1920's selected strains were tested. Local ecotypes of perennial rye grass were later certified and breeding of Wimmera rye grass has now been recommenced. In other states during the pre-war period local selections of perennial rye grass were made but these were not used commercially. In the post-war period selection and testing was resumed in Tasmania and the Tasmanian No. 1 strain has been released. Here further selections based on general combining ability and agronomic characters are being made to provide basic material for breeding an improved synthetic strain. A local ecotype of perennial rye grass selected in the Kangaroo Valley of New South Wales from an eighty year old stand of English rye grass is now being made more generally available through certification.

Phalaris—There have been various attempts at selection and breeding with *Phalaris tuberosa,* but no distinctive strains were established with the exception of one selected at the Waite Research Institute.

In addition to *P. tuberosa,* three other species, *P. minor, P. coerulescens* and *P. arundinacea,* are now recognized as potentially useful pasture plants. Extensive collections of these species are being tested at a number of centres and breeding has been initiated by the Division of Plant Industry of C.S.I.R.O. at Canberra and Wagga.

Intraspecific hybridization using top crossing together with a truncation selection programme, is being undertaken to make the best use of the variation present in the introductions of *P. tuberosa* and *P. coerulescens.*

Interspecific hybridization utilizing a range of parental types and followed by the production of alloploids is providing new synthetics. The alloploid *P. tuberosa* x *P. minor* produced by Hutton has already shown promise as a short term perennial for the wheat belt and a *P. tuberosa* x *P. arundinacea* hybrid has wide adaptability and a potential for high winter and summer production.

Cocksfoot—An extensive series of introductions from the Mediterranean and northern European areas is being tested and incorporated in a breeding programme at the Waite Agricultural Research Institute. A selection from this programme has shown great promise and is being extensively tested with a view to commercial use. Genetical and cytological studies are being incorporated with this work as well as studies of plant breeding methods.

Strain selection has been practised in all of the southern states and improved strains were developed in Victoria from locally adapted material, and in Western Australia from recent introductions.

Subtropical and tropical grasses

There have been some major achievements in the introduction of grasses suitable for the sub-tropics and tropics, notably the selection of introduced strains of buffel grass *(Cenchrus ciliaris).* Two strains are already in extensive use and newer introductions are being tested.

The most controversial species of recent years has undoubtedly been *Sorghum almum.* Until recently it was declared a noxious weed in New South Wales and a prohibited seed in Queensland because of its rhizomatous root system, its potential toxicity, and because its seed was indistinguishable from the weed, Johnson grass (*S. halepense).* The ban in New South Wales has recently been lifted. *Sorghum almum* has undoubted potential as a grass for subtropical pastures; the C.S.I.R.O. Division of Tropical Pastures advocates its use in areas having a predominantly summer rainfall in the 18-30 inch rainfall zone. *Sorghum almum* was first introduced from the Argentine in

1946, with further introductions in recent years. Selection and breeding if possible by the Department of Agriculture in New South Wales and the C.S.I.R.O. Division of Tropical Pastures aims to produce types with seed that can be more readily distinguished from that of Johnson grass, and with less rhizomatous root development, lower HCN content and improved drought resistance.

Introductions of *Paspalum, Chloris* and *Panicum* species are being tested and at the Division of Tropical Pastures efforts are being made to induce variability in *Paspalum dilitatum, P. scrobiculatum* and *P. plicatulum.* The apomictic reproduction of these species, in common with a large number of other subtropical grasses, makes the use of induced mutations potentially of great value.

Forest trees

A start has recently been made on the genetic improvement of Monterey pine *(Pinus radiata)* and slash pine *(P. elliottii).* Selected trees have been clonally propagated to establish "seed plantations" and progeny testing has been initiated. Studies of variability and estimates of heritability and of correlations among characters have been made by Fielding at the Forestry and Timber Bureau, Canberra.

Genetical studies have clarified some aspects of the taxonomy of *Eucalyptus* and some work aimed at genetic improvement has been initiated by Pryor in Canberra.

CONCLUSION

The period under review has seen steady, and indeed notable achievements in plant improvement. These have come from three main sources. Firstly, the introduction of varieties or strains of crop and pasture plants requiring little or no genetic adjustment, as in barley, rice, tobacco, safflower, flax and linseed, strawberry clover, *Centrosema pubescens,* cocksfoot, *Sorghum almum* and buffel grass, and numerous vegetable crops. Secondly, the selection of locally acclimatized varieties and strains as with white and subterranean clover, perennial rye grass, phalaris and cocksfoot, barrel medic, and various vegetables. And thirdly, the genetic adjustment by breeding and selection where the most outstanding achievements have been with wheat, sugar cane and maize.

However, a twenty-five year period, and particularly one interrupted by war, reaps only partial benefit from the effort invested. The gains from fresh introductions as well as from the revitalized breeding programmes with cereals, temperate grasses and legumes and the new programme with subtropical pasture species, tobacco, rice and other crops, are as yet only hopeful promises. Unfortunately, no work is in progress with several important species, among which are white clover, cotton, pineapples and bananas, and there is insufficient work with many others, including perennial rye grass, subtropical and tropical pasture and crop plants. Above all, a good deal more could be done on most of our crops in many more places.

The last twenty-five years have seen an increasing concentration and specialization of effort and for this trend to continue there must not only be increased funds but also an increased number of well trained plant breeders who are given the opportunity, the facilities and the environment for putting into practice modern knowledge and techniques.

Improved resources, including some provided by the new industry research funds for wheat, wool and tobacco, have already contributed materially to progress.

The genetic revolution that occurred in Australia in the post-war period has provided enhanced undergraduate and postgraduate training in genetics, and a number of centres are integrating practical plant breeding with research on breeding methods.

The infusion into breeding programmes of more extensive gene pools, including induced mutations, is providing new sources of variability, while genetical and biochemical studies of quantitative inheritance are providing new ways of handling polygenic variability in breeding programmes.

The plant breeder has long worked with

the pathologist and while his association with the ecologist, the physiologist and the biochemist is more recent, it has become none the less rewarding. Ecological, physiological and biochemical research, although not always directed to answer specifically the breeders' problems, are contributing to clearer definition of breeding objectives.

Plant improvement has become more precise and more dependent upon the integration of several disciplines for its success. This trend will undoubtedly continue and will demand of the plant breeder flexibility of approach, readiness to utilize new knowledge as it becomes available, and keenness to contribute to this knowledge in the way that only he can, by integrating research on breeding methods with his own breeding programme.

AGRICULTURAL SCIENCE
IN AUSTRALIA 1935-1960

ANIMAL IMPROVEMENT

J. M. RENDEL

When the experiments of Mendel became widely known there were great hopes for the application of the new knowledge of heredity to animal breeding. With few exceptions the immediate hopes were disappointed. Genetical knowledge could be applied successfully to a few characters which were due to single gene differences, and some widespread myths, which were already known to be incorrect, could be exploded even more completely. The inheritance of hornedness in cattle and sheep, feather colour in poultry, jaw defects in dogs and dwarfism of the type found in Kerry cattle are the sort of characters which could be explained and dealt with; telegony and lamarckism are myths which could be attacked from yet another point of view. But the main productive characters of domestic animals such as milk yield in dairy cattle, meat production in pigs and beef cattle, egg production in poultry and adaptation to new environments in all breeds seemed as far as ever beyond control by scientific methods of breeding.

In the first quarter of this century genetics dealt with characters which segregated into clear cut groups, the number of individuals in each group approximating to Mendelian ratios. Character differences which did not segregate into clear cut groups could not be analysed as controlled by one or more genes dominant or not, linked or not, the effect of each of which was known; and so predictions of the outcome of matings could not be made precisely. The geneticist could say about such characters that selective breeding would accumulate desirable genotypes. By so doing he confirmed the opinion of Darwinians and helped the previous position no more than by lending his authority to the view that selection, artificial or natural, is a powerful method of changing the nature of a breed or species. An understanding of the mechanism of heredity did not lend to direct application of genetics to animal breeding except in a very narrow field.

But the principles of Mendelian inheritance can be used to explore the consequences of selection and the past twenty-five years have been occupied in taking the first step in this direction. This work started from theoretical analyses of the effect of segregation on variation. Sir R. A. Fisher and Professor Sewal Wright both worked out the mathematical consequences of segregation on variation with different mating systems and population sizes. Further, taking into account the variation which the environment would introduce, they developed in much greater detail the concept of the correlation between relatives which had first been used by the early biometricians. By combining the dis-

tribution of gene differences, which must follow a Mendelian pattern, with the idea of correlation and variance they were able to formulate methods for assessing the extent to which a character is heritable and the expected breeding value of an individual or group. The way the expectations would be modified by inbreeding and variation in population size could also be predicted.

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The application of these ideas to animal breeding has followed the work of J. L. Lush and his school, the most notable member of which is I. M. Lerner. The concepts developed by this school and its followers all over the world are briefly these. The correlation between a measured trait in related individuals is known if the variation in the character is entirely heritable. The extent to which a correlation falls below expectation estimates the heritability of the character, that is the extent to which variation in it is genetic. Given the heritability of a character it is possible to say to what extent the superiority of a selected group is genetic; combination of phenotypic selection differential and heritability gives the genetic selection differential. This is an estimate of the breeding value of the individual or group. The expected breeding value of an individual can also be estimated from the breeding value of relatives. This is done by using the genetic correlation between relatives; the breeding value of dairy bulls and cockerels of egg laying breeds can be estimated from female relatives. By these procedures breeding programs can be outlined and their effects predicted for production characters. Predictions will be reliable so long as the heritability originally calculated still holds. Correlations between characters will often have to be taken into account. These are of two kinds, environmental and genetic, and can be separated in much the same way as heritability is calculated. A genetic correlation, positive or negative between two characters indicates that selection for one will also change the other. It is not appropriate in this article to go into further details.

There have been two main results from this approach. First, mating systems have been elaborated which have, within limits, given predictable results and which are far more effective than those of the past. Above all there is a set of objective criteria by which to choose between mating systems. Second, a lot of attention has been directed towards the details of the productive characters and emphasis in breeding has been directed towards these rather than towards hopeful but irrelevant characters of no economic importance. This last trend has not gone far enough in practical breeding of cattle and sheep but has gained much ground in breeding poultry and pigs. It is a little disheartening to be able to write that one of the achievements of the last twenty-five years has been to interest poultry breeders in the number of eggs laid by their birds instead of the colour of the eyes, and that in sheep breeding or cattle breeding, the shape of the head is still regarded by many as of more value than the amount of wool cut from a sheep or the growth rate of a steer. These characters are still not measured accurately by all stud breeders. However, from the scientific point of view, particularly in Australia, the detailed analysis of productive characters is taking an ever increasing fraction of the attention of animal breeders. The design of breeding plans can now be formulated effectively, up to a point. When a lot more is known about the development of the components of productive characters, their variation, and the genetic control of the latter, more effective breeding methods may become available. It is in this field that scientific advances may be expected in the next twenty-five years. The readily available and simple genetic variations can be handled. What does one do with the more complex interactions? The progress of research in animal breeding has been like the unfolding of a Chinese puzzle. Mendel opened the first

box. The second has been opened in the past twenty-five years only to reveal fresh complexities awaiting us inside.

POULTRY

The greatest difficulty encountered by poultry breeders in the pre-war years was lack of adequate advice on breeding techniques. The theories of Wright and Fisher, adapted for use in animal breeding by Lush, were still hard to apply. Nevertheless, information was steadily being accumulated in the United States on the efficacy of progeny and family testing as aids to improving characters of low and intermediate heritability. The concept of the hen housed average as a criterion for selection had also been introduced. Even though these theories had been applied to poultry breeding by Lerner and others, and shown to be successful in promoting genetic gains over a period of a dozen years, it was not until the C.S.I.R.O. Poultry Research Centre had been established at Werribee that this knowledge was steadily fed into the Industry. It is regrettable that despite this development of propaganda, which was directed towards the breeders in the early 1950's, little or no response was forthcoming and breeding continued to be, fortunately for only another four or five years, nothing more than propagation by mass selection.

Even though effective breeding work was negligible during the war years and right up to the mid-fifties it must not be thought that the Industry had remained quiescent throughout these years. In fact, something in the nature of a revolution had occurred. The whole commercial industry, in the space of less than a decade, had become based on crossbreds (mainly Leghorn x Australorps) whereas previously the White Leghorn breed probably accounted for 80 per cent. of all commercial flocks.

As early as 1951 sufficient evidence had been obtained at Werribee to indicate that crossbreeding involving the White Leghorn and Australorp breeds would give a lift of approximately two dozen eggs over the performance of the better parent breed. Subsequent results from Werribee indicated this margin of superiority could be maintained for a considerable period, even though the pure breeds were being improved in their production by suitable breeding techniques. Thus, not only was it evident that considerable gain could be obtained by crossbreeding, but also that this gain need not be a static one. Breeders were once more encouraged to apply orthodox breeding methods to their pure breeds with the ultimate aim of passing any such improvement through to the crossbreds. As mentioned previously, the advice was not accepted, possibly because of lack of facilities and inadequate understanding of modern breeding techniques, but principally because there was no great urgency to leave the conservative path traversed during the past two decades. It was not, until 1955, that the breeders and hatcherymen in the state of Victoria accepted the fact that they must start to breed; in other states this realisation did not come until two years later.

Perhaps the greatest impetus to effective poultry breeding can be traced to the meetings of the Technical Sub-Committee on Poultry Production in Perth, 1954 and in Melbourne, 1955. At the Perth meeting the idea of a Poultry Improvement Plan was discussed and accepted in principle. Subsequently, in Melbourne, a detailed plan was formulated and accepted by all states and the Commonwealth Government as a basis for lifting poultry production in the country. This plan, amongst other things, embraced the development of random sample tests in all states whereby the quality of breeders' stock could be appraised in a relatively uniform environment. Such random sample tests are now in operation in all states and are stimulating a great deal of interest not only amongst the breeders and hatcherymen but also throughout the poultry industry. As part of the Poultry Improvement Plan certain states also accepted the idea of accreditation. This amounted to putting the government seal of approval on such flocks as performed at a certain level in successive random sample tests. These new moves had the overall effect

of stimulating tremendous zeal and competitive spirit amongst the breeders. In 1958 a large commercial organisation in New South Wales announced that it had added to its staff a graduate trained in poultry breeding. It was not long before another group also succeeded in obtaining the services of a full-time poultry breeder and it is anticipated that further action, along these lines, will be taken in the near future.

As a result of these activities it is becoming clear that the Australian poultry industry is already following the American pattern. Certain of the large breeding organisations have extended their influence into other states, by means of franchised hatcheries and multiplication farms, and this has even extended to New Zealand. All this is, of course, to the advantage of the poultry industry as these organisations are in a position to carry out their breeding work at a high level because of the skilled and experienced technicians in their employment.

This brief summary of the progress made in poultry breeding in recent years would not be complete without mention of the steps which are currently being undertaken to develop quick growing meat birds. For the first time attention is being given to the development of a fast feathering, rapid growing, white feathered bird for table use. These birds are commonly known as broilers and many of the large breeding organisations in Australia are devoting a large proportion of their resources to the synthesising of broiler strains. Considerable success should be had in the space of a few years as the characters, for which selection is imposed, are generally highly heritable and are measurable in both sexes.

SHEEP

The breeder of wool sheep has no genetic difficulties to surmount. It is criteria for selection which are lacking in practice. An enormous amount of work has now been done in Australia on sheep skin and the way it grows its hair fibres. This started with the work of Carter and has received great impetus from the theoretical analyses of Fraser. The accumulation of staff and facilities for this work was one of the many achievements of Sir Ian Clunies Ross. The problem of breeding wool sheep is made simpler to handle by the organisation of the breeding industry which was outlined in 1955 by Short and Carter. This outline showed clearly that the pyramidal structure of the studs and the one-way movement of genetic material from the top (parent) studs to lower echelons and out into commercial flocks makes it possible to improve the whole of the Australian sheep population by working on only a few, say 30, parent studs.

The work of Turner at C.S.I.R.O.'s sheep breeding station, Gilruth Plains, and of the N.S.W. Department of Agriculture at Trangie started by Morley, has shown that simple selection for the right characters can increase the amount of wool produced by a sheep and the efficiency of its production. At the same time the wool produced can be, at the will of the breeder, of almost any combination of length, diameter and crimp desired. Future advances are still likely to be in the direction of refining criteria for selection, providing breeders with facilities for measuring these and persuading them to use the criteria in selective breeding. The work done on wool is being expanded to cover efficiency of food utilisation, grazing habits, fertility and so on, any one of which qualities might become an important character in breeding.

At the Conference on Fleece Measurement for Flock Improvement (Sydney, May 1954) state and C.S.I.R.O. work was brought together and from it sprang the decision to expand fleece measurement facilities in each state and to further the use of these facilities, particularly by stud-breeders.

A list of existing facilities is given in Appendix C of the Report of the Hawkesbury Conference (1958) to the Standing Committee on Agriculture. In terms of timing the Queensland Department of Agriculture far outstripped the other states in carrying facilities

and advice to the woolgrower, and had a considerable program under way as early as 1952; a program which covered a significant proportion of ram-breeding flocks by 1954. Queensland also led the way with short-course "Schools for wool-growers" with straightforward instruction and demonstration coupled with "participation tests" to demonstrate particularly the advantages of measurement over assessment by eye. These courses were so successful that the Queensland Merino Stud Breeders Association requested that several be organised for stud-breeders; these courses have proved a continuing success and an object lesson to all other states and sheep-breeders.

It is clear that in some states the mere existence of facilities is of no direct benefit to breeders, since the research units attached thereto, utilize them to the full. Western Australia is relatively poorly equipped, though since 1958 some facilities for fleece weighing and scouring have been made available by the Western Australian Department of Agriculture. Tasmania has very little, and depends almost entirely on the Geelong Institute which, since 1958, has considerably expanded its facilities to include scouring, and staple length measurements as well as diameter.

In New South Wales the government instrumentalities are fully occupied with their own programs, but the N.S.W. University (McMahon and Roberts) has steadily expanded its capacity to assist the industry since 1954 and at present copes with measurements for many of our leading studs.

In Queensland since 1952 the Queensland Department has offered substantial facilities for fleece measurement, extension service, and short-course schools for breeders and wool-growers. These can cope with a major proportion of the requirements of Queensland ram-breeders.

South Australia now has facilities for coping with a major proportion of their ram-breeding flocks and it is proposed that the South Australian Department of Agriculture makes a major effort with fleece measurement during 1960 and the following years.

Any increase in quantity or improvement in quality of the national clip which might have come from the use of fleece measurement in selection is, of course, still swamped by large year to year variations and overshadowed by changes due to improved pasture, rabbit control, and husbandry practices. Nonetheless, the adoption of more realistic methods of selection by the leading stud breeders will undoubtedly become more and more important and is also an extremely economic way for the national clip to be improved. The fast-spreading realization of this fact amongst those who produce the rams for the national flock (stud-breeders) is the outstanding achievement of those who have studied the fleece.

CATTLE

When breeding dairy cattle for milk and fat production, selection amongst femalesf is severely restricted by the slow rate of reproduction. A cow is unlikely on average to have more than two or three daughters reaching maturity and producing one lactation. This puts an upper limit to culling. As some cows are culled for physical defects, selection for milk yield cannot be very intense. Males can be assessed on their female relatives' merit, and most effectively by progeny comparisons. But as a large fraction of variation, about 90 per cent., between herds is due to differences in management, accurate assessments can only be made from comparisons between cows of the same herd. Progeny testing is therefore very difficult. Some ingenious methods of sire survey have been devised, notably in New Zealand, and these are now in use in Australia. The perfection of artificial insemination has given breeders their best chance of herd improvement. Bulls used at artificial insemination centres can be assessed relative to one another with great precision and if this assessment is used to choose sires of future sires, progress greatly in access of anything seen in the past can be expected. As the structure of dairy herds is pyramidal, like the structure of sheep flocks, improvements in quite a small section of the industry will affect the whole.

The possible use of artificial insemination centres for bull proving and bull breeding has only been appreciated recently. The first A.I. services in Australia were developed in 1945 on an experimental basis by both the Victorian and New South Wales Departments of Agriculture. The Victorian unit was maintained on an experimental basis until 1956, when frozen semen from Werribee was offered to farmer groups prepared to establish and operate their own inseminating units. 21 such units were operating in 1959 and about 30,000 cows were inseminated. The control of this program in Victoria will pass to the Victorian Artificial Breeders' Co-operative Society Ltd., in 1961. At present, this organisation is constituted to provide a commercial A.I. service.

A commercial A.I. centre was opened by the New South Wales Department of Agriculture in 1952. A second commercial centre in New South Wales, controlled by the Hunter Valley Co-operative Dairy Society Ltd., commenced operations in 1953.

Responsibility for the development of A.I. services in New South Wales was vested in the N.S.W. Milk Board in 1956 when the Board took control of these two centres. This body has decided to incorporate a bull breeding and bull proving scheme into its activities and has taken preliminary steps for the development of the scheme. Selection of bulls for use in A.I. both in New South Wales and Victoria, has up to now been based on available production records of relatives. Therefore, although commercial A.I. units have been developed, they have not yet begun to contribute much to the genetic improvement of the dairy herds they service.

Artificial insemination services in Queensland date from 1955, when a bull-proving scheme was inaugurated for the purpose of locating dairy sires of outstanding genetic merit from Queensland studs. This scheme has been developed for the Jersey and Australian Illawarra Shorthorn breeds. Daughters of the first four Jersey bulls tested have completed their first lactations. These bulls have been compared on the basis of the average daughter production, corrected for herd average of the farm on which each daughter made her record.

The first two bulls chosen as the best are now in use at a commercial A.I. centre at Atherton and although four bulls of each breed are continuing to be tested each year, no definite plans have been formulated for the usage of these bulls, once progeny records are available.

In developing these bull proving programs, some consideration of milk quality will have to be made. In recent years, an increasing proportion of dairy production is being marketed as liquid milk. As a result, the emphasis has been placed mainly on increasing milk yields. Although the minimum legal limit for Solids-not-Fat in New South Wales is 8.5 per cent., milk for metropolitan supply from the South Coast averages from 8.2 to 8.5 per cent., while individual suppliers are known to consistently supply milk with an average S.N.F. as low as 8.0 per cent. This same problem exists elsewhere in Australia. There is evidence that nutritional status of the cow influences the S.N.F. content of her milk, and this no doubt is a factor contributing to low S.N.F. in milk from many producers. However, S.N.F. content is determined by genetic factors to some extent (Robertson, Waite and White, 1956) and improvement could be obtained by selective breeding.

Australia is faced with the problem of maintaining dairy herds in high environmental temperatures. The question of what sort of cattle are ideally suited for producing milk in the heat is one which has recently been taken up by C.S.I.R.O., who have been presented with some Sindhi and Sahiwal stock by the Pakistan Government. These are the basis of an experiment to determine how to breed cattle for hot climates. The genetic principles will be just the same as in breeding dairy cattle in any other climate; the characters of importance may prove to be different.

The breeding of beef cattle has proved little trouble except in the north. It is now recognised that the British breeds in their present form are not suited to beef production in northern environments. Crossbred cattle

produced by mating British breeds to Zebu types first introduced in any scale in 1931, can be marketed at 1000 lb live weight a year or more earlier than their British half sibs. Studies by C.S.I.R.O. at the Australian Meat Board's beef cattle research station at Belmont near Rockhampton have shown that growth rate in that environment is associated with body temperature and coat type. The obvious superiority of crossbreds in the northern environment should not lead people to the conclusion that the British breeds are finished in the north. They are in their present form but there is no reason to suppose that they cannot be improved for northern climates by proper selective breeding. If attention is paid primarily to growth rate after weaning in the north, ability to maintain a low body temperature and coat type, it should be possible to breed strains capable of doing as well in the north as the parent strains do in the south. It will be interesting to see during the next twenty-five years whether graziers in the north will swing over to stock of crossbred origin or whether the breeders will develop pure strains adapted to northern conditions from the existing breeds. One breeder of Shorthorns has already made great strides in this direction and can market pure Shorthorns at 550-600 lb carcase weight at two years.

CONCLUSION

In conclusion, the past twenty-five years has seen the first practical application of Mendelian genetics to selective breeding. The methods have been formulated largely by Lush and his disciples. In Australia a lot of work has been done to build up machinery which can explore different breeds of livestock for the characters which should be selected. Some, but rather less has gone into providing breeders with facilities for measuring these characters in their stock. A lot remains to be done to get the practical breeder on to the right lines in all livestock breeding with the exception of poultry where much progress has been made though a lot still remains to be done. The next twenty-five years will see a great harvest if work is done to secure it.

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AGRICULTURAL SCIENCE
IN AUSTRALIA 1935-1960

PLANT PROTECTION

B. A. B. EDWARDS and
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Plant protection is essentially aimed at securing the maximum return from each rural acre, by enabling the producer to obtain economical control of pests and diseases.

The methods available are continually improving with gains in knowledge and in this review we have attempted to present the most notable of these advances in recent years and to assess their present and possible future use in plant protection in Australia.

PESTICIDES

The meteoric rise of the organic pesticides has been a marked feature of plant protection since the 1930's. For the fungicides this was ushered in by U.S. Patent 1,972,961 of Tisdale and Williams in 1934 on the alkyl dithiocarbamates notably thiram and ziram. Other classes of fungicides followed in quick succession, hand in hand with the development of rapid laboratory screening techniques. The quinones, notably chloranil and dichlone, were developed. Then came the alkylene bisdithiocarbamates such as nabam, zineb and maneb. The nitrosopyrazoles, imidazolines (glyodin), Karathane, quinolines, perchloromethyl mercaptans (captan), organic mercurials, a few antibiotics also with action against bacteria, and more recently n-dodecyl guanidine acetate (Cyprex or Melprex) and oils entered the field. Many thousands of chemicals are screened, but few are chosen: most are too expensive, too phytotoxic, too labile or suffer from other defects.

Hitherto disease control had rested squarely on copper and sulphur, and in many instances it still does. However the organic fungicides have been responsible for a remarkable increase in yield and quality of many crops compared with copper and sulphur, and in some cases have afforded control previously lacking or insufficient.

The most commonly used insecticides prior to 1940 included lead arsenate, nicotine sulphate, pyrethrin and many fumigants (carbon bisulphide methyl bromide, etc.). The introduction of DDT in 1942 was undoubtedly the turning point in the chemical war on insects, and similar types of chemicals (chlorinated hydro-carbons) such as BHC, toxaphene, chlordane, dieldrin and aldrin followed in rapid succession.

A second and newer group, the organic phosphorus compounds, have been developed since the publication of the pioneer work by Schrader in 1947. Thousands of phosphorus compounds of many types have been evaluated

for insecticidal properties, and compounds commonly used commercially in Australia include: parathion, malathion, diazinon, Systox, Metasystox, Trithion and Gusathion.

The phosphorus group contains many compounds which are systemic in action such as Systox, Metasystox, and Sayfos and this type of action has caught and held the imagination of the users of insecticides. They see a distinct advantage in not having to completely cover-spray or, in being able to water an insecticide into the soil so that its uptake into the plant by roots will render the foliage toxic to insects. Another distinct advantage is of course the safety to insect predators and parasites from chemicals within the plant.

A much newer group of chemicals, the carbamates, of which Sevin is the most outstanding, have only recently been used in Australia. Other members of this group, e.g., Pyrolan, Isolan, while in use overseas have not been used extensively in this country.

An enormous amount of work has been done during the last twenty years on the evaluation of pesticides by the various Departments of Agriculture, the C.S.I.R.O. and certain commercial organisations. In the case of insecticides this has been accentuated by insect resistance and also because of diverse effects of insecticides on insect populations. The most notable example of both of these is that of DDT on orchard populations. The continued use of DDT over ten years has selected out and bred up a DDT resistant strain of codling moth and at the same time, by its effect on mite predators and parasites, resulted in a build up of a mite problem in most orchards.

The search for safer, cheaper and better pesticides continues, abetted by studies on their mode of action, the relationship between chemical structure and activity, and between physical properties and performance. The versatility of the organics was soon appreciated and molecular variations aimed at suitable properties are now commonplace. Even so new classes of pesticides are still discovered mainly by routine screening.

In Australia evaluation of pesticides has been accompanied by few attempts to discover new ones. This is largely a matter of economics: discovery is in the hands of chemical companies and it takes a large company to provide the necessary funds. As industry grows this imbalance may be remedied, and there are already signs that this is happening.

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THE PROBLEM OF RESISTANCE

"Resistance" has become one of the most popular reasons given for poor control of insects by chemicals. While it is true that some enormously important economic pests have developed genuine resistance by selection, most cases of so called resistance have been proved to be due to any one of a number of factors, e.g., poor spraying, incorrect time of application, and incorrect usage of chemicals. To prove resistance, a large amount of work, more often than not in the laboratory, is needed.

For fungi the story so far is much happier than for insects. While degrees of fungal resistance just as impressive as those for insects have been obtained in the laboratory, field control with fungicides appears to continue at a satisfactory level and the spectre of having to remove some fungicides from use on this account has not materialized.

While several cases of resistance or tolerance to insecticides, such as that of the California red scale *Aonidiella aurantii* to hydrogen cyanide fumigation, were reported before 1945, the worldwide occurrence of DDT resistance by the common housefly, *Musca domestica*, provided the first major demonstration of the importance of resistance in insect control. Since then, many cases of insect resistance, or more broadly arthropod resistance, to insecticides have been recorded in Australia. These include the resistance of the

sheep blowfly, *Lucilia cuprina,* and the common housefly, *Musca domestica,* to the chlorinated hydrocarbons, the codling moth, *Cydia pomonella,* to DDT, the cattle tick, *Boophilus microplus,* to arsenic and BHC and the red spider mites to organophosphorus compounds.

All of these occurrences have been of great importance, but perhaps the most spectacular has been the appearance of DDT-resistance in the codling moth. When introduced in 1946-47, DDT was hailed as the answer to this problem, a reduction in damaged fruit from 15 per cent. to as low as 0.01 per cent. being common. However in 1953-54, instances of failure of DDT to control codling moth occurred in South Australia and resistance was proved during the following two years. A similar phenomenon occurred in Victoria in 1956, in New South Wales in 1958 and at the time of writing resistance is also suspected in both Queensland and Tasmania. Fortunately the organo-phosphorus compounds such as parathion, malathion and Gusathion and the new carbamate compound Sevin have been proved effective against the codling moth and are in general use throughout these areas.

This setback to the comparatively easy methods of chemical control in the early DDT days has meant that much effort has had to be expended in studying the mechanics of resistance, alternative chemicals, life histories and biological and cultural methods of control. More cases of resistance will undoubtedly occur but it is confidently expected that with the prior knowledge built up in the cases to date, and with further concentrated effort, solutions to these problems will be found.

FORMULATION AND APPLICATION

To apply the new pesticides an impressive array of formulations and equipment has been developed.

The newer formulations including wettable powders, miscible oils, and mayonnaises have raised considerable phytotoxicity and performance problems. Generally the solvent formulations have been more risky, but often they have performed better than the wettable powders (for example against thrips) and they leave fewer visible residues. Combination sprays have brought problems of compatibility. The formulation team has become a major component of the pesticide industry.

Important developments in application have been aerial and drive-past spraying, both high and low volume. The former does many acres a minute and the latter two to three acres an hour compared with two to three acres a day for hand spraying. These developments have reduced spraying costs by savings in labour and material, and have allowed spray timings to be nearer the optimum. Both aerial and drive past spraying are highly effective against insects. For fungi aerial spraying is relatively poor except possibly for oils on bananas and fungicides on a few row crops, and drive past spraying is slightly less effective than hand spraying but with advantages outweighing disadvantages. Wet ground does not limit the former whereas it often severely limits the latter in Australia where orchards are not generally grassed down.

Much valuable work has been carried out on the physical behaviour of sprays, particle size, weathering and spray distribution patterns from various units in relation to insect and fungal behaviour, and we can look forward to further advances.

THE TIMING OF SPRAYS

A marked increase in knowledge on the life cycles of insects and fungi and on their incidence in relation to climatic conditions has allowed a few well-timed pesticide applications to replace a large number haphazardly applied with a great saving in costs. Many of these developments have depended greatly on development of spore traps, length of leaf wetness recorders, insect lure traps, and breeding stations.

In many countries warnings to spray are issued by government departments for diseases such as apple scab, potato late blight, tobacco

blue mould, vine downy mildew and others. Miller claims that their average correctness is about 80 per cent. Post infection disease control has been developed and the Mills system using organic mercury for apple scab is a notable example. Unfortunately it is limited by the phytotoxicity and toxic residues of mercury, and by the coincidence of the optimum spraying time with wet ground, making spraying difficult. Materials safer than mercury are required and n-dodecyl guanidine acetate shows promise.

In Australia disease forecasting and post infection control are relatively undeveloped, but they should advance as the necessary basic information is acquired. The Mills system has been tried with success in some areas. The control of apple and pear scab by an autumn application of PMC developed in N.S.W. is promising, and could revolutionize control if effective on a large scale. We have other diseases, such as tobacco blue mould and wheat rust against which we have fungicides, proved effective in small scale tests. It is possible that these fungicides might work economically in the field in conjunction with effective forecasting systems.

As a basis for determining the need and type of action required to combat insect pests, insect surveys are carried out in overseas countries, particularly in the United States. They are used in that country to issue advice to farmers on the timing of sprays; two important pests against which this information is issued are the hessian fly on wheat and the corn maggot.

Locally, several departments of Agriculture regularly issue spray notices for codling moth and oriental fruit moth based on peak emergences. When followed precisely these have generally given excellent crops whose additional value has exceeded by far that of the spray costs. Unfortunately many growers ignore or follow the notices incompletely, and do not spray until the pests have reached plague proportions. Then they blame the chemical for the lack of control. This is a matter of education, and it is felt that there are many more cases where spray notices could be profitably issued.

BIOLOGICAL CONTROL

This aspect of control is one which has held popular appeal for many years because, where successful, the ravages of the pest can be effectively checked at low cost. While some notable successes have been achieved in the past it must also be realized that there have also been a great many failures in this field.

The outstanding achievement in biological control in Australia has undoubtedly been the wiping out in 1926 of prickly pear, by the moth *Cactoblastis* and its allies, from an infestation of some 60 million acres in Queensland and New South Wales to the rarity which it is today. This success brought an immediate demand from orchardists and farmers for the introduction of other parasites and predators, mainly to control insect pests. The work was taken up by C.S.I.R.O. in conjunction with the various State Departments of Agriculture and many introductions have been made into Australia.

While none of these liberations can be said to have been completely successful, some of them, in the right environment and conditions, certainly had a marked effect on the pest species. One typical case is the wasp parasite *Aphelinus mali* introduced into Tasmania in 1922 to control the woolly apple aphid *Eriosoma lanigerum*. A high level of parasitisation does occur but in general lags some months behind the woolly aphid populations allowing economic damage to be done to the apple trees. This is because the developmental period of the parasite is much longer in the cooler temperatures of spring and early summer whereas that of the aphid does not vary between spring and summer. In the warmer mainland areas in Victoria and New South Wales, *Aphelinus* appears to give satisfactory control of woolly aphid.

Parasites have also been introduced for the cabbage white butterfly, the cabbage moth, the green vegetable bug, the canary fly, and fruit flies, but in nearly all these cases supplementary measures of chemical or cultural control are still being used.

Many cases of pathogenic microorganisms infecting insects have been discovered during the last few years and experiments using them

have been made in many countries. Most of these field tests have been conducted with bacteria and viruses because the extreme dependence of the remainder, such as Rickettsiae, fungi, protozoa and nematodes, on environmental conditions makes them unsuitable organisms. Nearly all these pathogens are known to be present in Australia but little or no work has been attempted on them.

Of popular interest at the moment is the bacterium *Bacillus thuringiensis* the spores of which are highly toxic to many caterpillars. So far the degree of control attained has not been equal to that obtained with chemicals but it may prove a useful adjunct if resistance or residue problems arise.

At the present time then, many parasites and predators of insects have been introduced into Australia while little work has been attempted on pathogenic organisms infecting insects. In the vast majority of cases biological control can only partially be successful, and to attain commercial control of the pest concerned, supplementary measures must be applied. These may be either cultural or chemical and if the latter, should be aimed, by correct timing, at bringing about the least possible mortality of any beneficial organisms which may be present.

AIR-BORNE DISEASES

The study of fungal and host physiology, life cycles, host factors of resistance, spore survival and transport, infection conditions, host/parasite relations, and allied fields has proceeded apace overseas and contributed much to the control of air-borne diseases. Research of this nature appears to have passed a dormant period in Australia and now promises to blossom.

We have not been slow to adopt the new fungicides for foliage application. Thiram and captan are widely used for apple scab. Thiram and ziram have replaced the acid swabbing-Bordeaux schedule for vine black spot (*Elsinoe ampelina*) and zineb finds some use for downy mildew. Zineb is increasingly used for tomatoes and considerable yield increases have been demonstrated. Karathane is becoming popular for apple powdery mildew. The organic mercurials such as PMC and PMF have found favour on apples and pears in some districts, but are restricted by their toxicity to plants and humans. Most of the new foliage sprays can be safely used at times found dangerous for copper and sulphur. Some have greater compatibility than copper or sulphur. But they have brought problems: through replacing sulphur they have encouraged a build-up of apple powdery mildew and acarina. Many do not weather as well as copper and have to be applied more often.

Despite many advances there are still serious gaps in the armoury. Tobacco blue mould, adequately controlled by benzol in the seed bed, is a major factor limiting production in the field and no fungicide examined has achieved consistently good control. We are not really on top of apple powdery mildew in several areas. Brown rot of stone fruits is still a major problem. Several bacterial diseases such as those caused by *Pseudomonas syringae* lack a really effective means of control. We may have to find an economic control of wheat rust. Systemic infections, so economically important for fruit trees, such as apricot gummosis, await systemic fungicides or bacteriacides, but suitable materials appear to be lacking despite an intensive search overseas. The systemic properties of some of the antibiotics fathered hopes, but for the most part these have been dashed. The more promising appear active against bacteria, so there is great need for cheap antibiotics active against fungi.

Let us hope that intractable problems of the type above will stimulate local investigation not only on chemicals but also on basic factors of the type already enunciated.

THE SOIL

The soil, for long relatively neglected for control of pests and diseases by contrast with above ground control, has been increasingly investigated in recent years and some pathologists and entomologists now spend most of their working life "underground".

In the field of root disease the two earlier phases of etiology and environmental studies have led to that of microbial ecology (Garrett) from which the most outstanding advances have come in the past 25 years. Concepts such as the rhizosphere, soil inhabitants versus soil invaders and inoculum potential are only a few of the headlines of progress, influencing not only their field of origin but also plant pathological concepts in general.

The knowledge recently amassed has led to a better understanding and application of cultural plant protection measures, viz., fertilizer and manurial treatments, crop rotation, pest and disease avoidance. The role of the soil toxicants is not as clear cut. The simple factor of their considerable dilution by the soil together with interaction with its complex and varying constituents makes the task of the toxicants more difficult in the soil than on the leaf. As a rule more success has been achieved where a narrow zone of activity is required. This has applied to seed dressings, potato and cane-sett treatments, transplants and row treatments and to volatile chemicals capable of efficient soil migration.

Many fungicides, e.g., thiram, captan and dichlone are active against soil pathogens such as damping-off fungi and root rots. Some have marked specificity, viz., PCNB is effective against *Rhizoctonia,* but not against *Pythium.* Unfortunately the effective rates in row or broadcast treatments are too expensive for the Australian agricultural economy and their use appears limited to seed dressings or seed beds. Some of the antibiotics have shown promise in glasshouse tests, but are readily inactivated in many types of soils, and thinking now favours stimulation of the production of the right antibiotics by the soil microflora or foliar application in the hope of migration to the roots.

Insect control by chemicals on the top of or in the soil is not new, but it had little practical significance before the advent of DDT and the newer chlorinated hydrocarbons. True, there were soil insecticides used before this, but of the commonest, arsenic, tended to be more toxic to vegetation than to insects; the insecticides obtained from plants (e.g., pyrethrins) are too unstable, and soil fumigants, although very effective against insects, are too costly under most circumstances. Again, and perhaps more so than in other fields of insect control, an exact knowledge of the life history of the pest concerned is essential so that treatments can be applied at the most susceptible stage of the insects' life.

By and large the insecticides, as sprays, dusts or granules, can boast of more economically effective treatments than the fungicides as row or broadcast applications. The excellent control of the greyback sugarcane beetle is a good example of a successful row treatment, while the use of DDT for pasture grubs and red legged earth mite and malathion for lucerne flea typify broadcast treatments.

It is doubtful whether any other field of plant protection has shown such a high return for so small an investment as the seed dressings. Corn seed treatment in the United States yields about three bushels or $5 for an expenditure of 4 cents an acre and 30 cents an acre for dressing may increase spinach yield by $50 an acre. For cereals the few mercurials in use earlier have been largely replaced by a wide range of organic variants for the control of bunt and some other fungi and bacteria; but these have not proved as effective for damping-off and root-rot fungi as say thiram or captan. The human toxicity of the mercurials has been a constant worry and many attempts have been made to find less toxic chemicals. Apart from hexachlorbenzene, specific against wheat bunt, the search has been unsuccessful and there is a great need for a new group of fungicides. A changeover from dusts to slurry and liquid formulations has occurred in many areas, and while this sometimes has advantages, it is not the complete answer. Combinations of mercury with lindane, aldrin, dieldrin or heptachlor have proved most useful overseas for wireworms and other soil insects; but have not been used extensively in Australia. We know we have a wireworm, or false wireworm, problem in Australia, but its extent has not been explored.

The limited sphere of action of our fungicidal seed dressings is a major shortcoming and frequently good emergence is vitiated by the invasion of roots growing beyond their zone of action. Since row or broadcast applica-

tions are often ineffective or uneconomic it is easy to see why thinking favours the development of systemics even though this appears most difficult. The development overseas of systemic insecticidal dressings like Thimet and Sayfos, which migrate into the emerging seedling and give it several weeks' protection from aphid or mite attack, is a ray of light. Can we not develop fungicides which behave similarly and migrate to the roots?

We know little of the ravages of soil insects in Australia and much more work is needed on life histories, taxonomy and resultant damage. While we have systemic and non-systemic insecticides capable of being used as seed dressings and some of the newer organophosphorus compounds also show promise as soil insecticides, little has so far been attempted with them in this country.

NEMATODES

Nematology, hitherto frequently disowned by both entomologists and plant pathologists, has developed into a system of knowledge in its own right, and nematologists are now well established members of the plant protection fraternity. This has led to a great increase in basic knowledge, the development of nematocides, and an appreciation of the economic importance of nematodes in many crops.

Carbon bisulphide and chloropicrin have partly yielded to new materials like DD mixture (dichloropropane-dichloropropene) ethylene dibromide (EDB), and methyl bromide. More recently organophosphates, Vapam (sodium N-methyl dithiocarbamate), Mylone or N-521 (3,5-dimethyltetrahydro — 1,3,5,2H thiadiazine-2-thione) and Nemagon or Fumazone (1,2-dibromo-3-chloropropane) have entered the field. Cost-efficiency, phytotoxicity and difficulty of application have greatly limited their use. In the United States less than 1 per cent. of the field crops known to have a nematode problem receive nematocides, and generally their application is considered rather marginal. In Australia EDB has cost about £16 per acre for material alone, so use has been limited to valuable crops like tobacco and tomatoes. A recent reduction to about £10 per acre should open up wider use.

For glasshouses and seedbeds expensive products like Vapam are economic and frequently cheaper than steam. Activity against weed seeds and fungi is an additional advantage in some cases.

Large scale application has led to the development of mobile injection equipment. As an alternative some of the liquid nematocides have been adsorbed on diluents for distribution by fertilizer equipment, but opinion is still divided on their efficiency. A few have been made up as wettable powders for application as suspensions, but it is difficult to get penetration through the upper zone of the soil.

The importance of nematodes on perennial crops is being increasingly recognized, but control is being delayed by lack of nematocides safe *in situ*. Nemagon has shown promise in some cases. There is great need for developments here.

Most of the present nematocides effectively reduce the nematode population for only a season; and materials of long residual action appear worth exploring bearing in mind that physical properties necessary for effective distribution also make products evanescent. More widespread use of nematocides on less valuable crops must await the development of cheaper materials and a better understanding of the problem. Possibly the latter will lead to a novel method of attack.

THE PLANT VIRUSES

In the period of review the virus field appears to have developed almost exponentially. Indicator plants, antiserum techniques, isolation of viruses, some understanding of their physical and chemical structure aided by the electron microscope and ultracentrifuge, their reconstitution, and vector-virus-host complex studies, are but some of the developments. In Australia virus work has been of a high standard but it has lacked quantity and diversity. Work has largely concerned the practical problems of virus recognition and transmission studies, but more attention is now being given to the fundamental side.

What controls have been developed along with these advances in knowledge? Breeding for resistance has scored successes but is ever behind needs. The issuing of virus-free-stock, certification schemes, and the destruction of infected plants have been highly developed in some countries with major economic benefit. Our potato seed tuber certification, banana bunchy top eradication, citrus bud certification, strawberry runner scheme and cane sett control have been most beneficial.

Attempts to control viruses by vector control have met with only limited success. DDT was tried as soon as it became available. It gave useful control of tomato spotted wilt by controlling thrips; but it was useless against vectors of many other viruses. The systemic insecticides show more promise, e.g., against cacao swollen shoot and viruses of row crops without harm to many beneficial insects. The systemic seed dressings like Thimet and Sayfos open up interesting possibilities. We now know that there is more chance of control when vectors have to feed for a long time to become infective and in these cases repellents appear a sound approach.

For direct control of viruses heat treatment has proved most useful though limited in application. Chemicals have been one of our most conspicuous plant protection failures and we have not gone beyond laboratory curiosities to large scale use.

Crop propagation by vegetative methods rather than seeds, intensive agriculture promoted indeed by plant protection, and rapid international movement of plants beyond the capacity of existing quarantine, suggest that the virus problem will increase in intensity. This must not be confused with recognition of viruses which were "there all the time." None of the methods discussed above has outstanding general utility: we hopefully await a major advance in basic knowledge.

STORAGE AND TRANSPORT PROBLEMS

Many of our storage and transit rots are influenced by pre-harvest plant protection measures, and brown rot of stone fruit is probably the most important. Undoubtedly, pre-harvest applications of newer fungicides give economic control under certain conditions, but often are no better than sulphur and are frequently inadequate on late canning and dessert varieties. Latent infections below the penetration of fungicides have been implicated for apricots; but for peaches the position is less clear and the high spore burden on the inadequately wetted fruit has been blamed. Numerous fungicidal dips and gaseous products like trichlorethylene have been tried and found wanting. High temperature storage at 94° shows promise, but whether this will be adopted by canneries remains to be seen. Measures effective against brown rot are often ineffective against transit rot (*Rhizopus* sp.). More work is needed on fumigant fungicides, preharvest sprays and heat storage.

In the past 25 years successful dips such as salicylanilide for squirter (*Nigrospora sphaerica*) of bananas, 2,4D and salicylanilide for stem end rot (*Phomopsis citri*) of lemons, and sodium orthophenyl phenate for green mould (*Penicillium digitatum*) of oranges have been developed and are now standard practice in some areas. Diphenyl wraps have also come into use for oranges, and microcrystalline wax dips are either in use or being explored for oranges, bananas, passion fruit and other fruits. Target spot (*Gleosporium album*) of apples has been controlled by pre-harvest applications of captan. Notable work has been carried out on storage diseases and disorders of apples. Moulding of drying grapes on the racks, despite much effort, remains an intractable problem. Control can be obtained with sulphur, but the material involves much trouble and labour. In Australia, as overseas, there is a major need for a general fungicide dip for edible products which would leave a residue with a wide safety margin for the consumer. Sorbic acid is in this class, but unfortunately its fungicidal spectrum is far too narrow.

The damage caused by insects to stored products is often inconspicuous due to inaccessibility. By contrast with insects in crops, where the farmer may take remedial measures or where losses may be balanced by an increase in yield of surviving plants, losses in stored products are often irrevocable and not evident until the products are removed from store. This problem is extremely important in Australia where large stocks of grain and dried

fruit may accumulate or are transported over long distances.

There are many methods of control which have been used at one time or another in Australia. Hygiene or the thorough cleaning of all silos, mills, etc., at regular intervals before bringing in clean produce can be one of the major factors in pest free produce and is often used in conjunction with contact insecticides in the form of dusts, sprays or smokes. These chemicals include DDT, lindane, and pyrethrins.

Fumigation has long been in use and the brominated or chlorinated aliphatic hydrocarbons such as methyl bromide are now extensively used. Recent research has also been directed towards better circulation of fumigants either by improved storing, forced circulation or by the use of a vacuum. Control of insects by sealed storage has also received some attention, the insects being killed by the depletion of oxygen and accumulation of carbon dioxide.

There remain many problems to be solved in this field, including the specificity of the insecticides in common use, the evaluation of many new insecticides and fumigants for use on or near stored foodstuffs and the levels of contamination which can be expected in normal use. More specialists on stored products entomology are required in Australia, as too often in the past this problem has been left to the spare time of the agricultural entomologist already overburdened with problems concerned with the cultivation of crops.

THE ORGANIZATION OF PLANT PROTECTION IN AUSTRALIA

The organization of plant protection has developed considerably over the past 25 years. The work of the Departments of Agriculture covers some fundamental problems, extension, quarantine, certification, and the testing of new products in fields of major economic importance. The C.S.I.R.O. and the universities concentrate more on the fundamental side. On the other hand, the local pesticide industry is concerned primarily with the short range development of new pesticides and in recent years has greatly improved its research development facilities.

The Department of Health in conjunction with the Departments of Agriculture, has actively developed quarantine, and is taking an increasing interest in health aspects of pesticides. As yet we have no equivalent of the United States Miller Bill in Australia and policing of residues is still somewhat lax. At least we are still free from the undesirable witch-hunting which has accompanied the administration of this bill in the United States. Various fungicide and pesticide acts exercise some control over active ingredients; but there is no policy of standards in the fullest sense, and no official routine biological testing of products as in New Zealand. State registration control varies considerably and causes much confusion. Products are acceptable in one state but not in another, and manufacturers have to produce several different labels for the one product. Long overdue reforms are now in hand.

EPILOGUE

Economic entomology and plant pathology in Australia at the moment are at a crossroads. In the past 25 years, particularly in North America, there has been a strong emphasis on all out chemical warfare but it is becoming increasingly evident that all fields of plant protection are interrelated and are based on husbandry. Chemicals are becoming more expensive to discover and develop and some useful ones are falling by the way due to the development of resistant organisms. It may be that the law of diminishing returns is operating on new chemicals. Will the further use of chemicals have to await fundamental advances or will we have to rely more on other fields in the next 25 years? This may or may not be so, but at present there is no sign of a cessation of the flow of new compounds offering greater advantages in efficiency, safety or in other ways, over those at present in use. It seems likely that in future, advances in all fields, and additions to both our fundamental and empirical knowledge, will continue to combine to give us still better control of pests and diseases.

WATER

A. L. TISDALL

Ultimately, the limiting factor in determining the population that can be supported in this country is water. Australia is the driest of all continents, with a big area, about a fifth of the total, which has no rivers, and a comparable area where the rivers are intermittent. Only a fringe near the coast in the north and east with comparatively small areas in the south-east and south-west have an annual rainfall of over 40 inches.

WATER CONSERVATION

As would be expected in such a climate, a great deal of attention has been paid to water conservation, and it may be of interest to discuss the principal aspects which have received the attention of workers in this field.

Large storages

Our main development has been in surface water resources, and although the beginnings of irrigation in this country go back nearly a century, most of the larger storages have been built in the last twenty-five years. Each generation sees more large projects developed, projects which were not financially possible to an earlier generation, and no doubt more rivers will be harnessed in the future. Naturally, the best dam-sites are chosen first, and further works will be more and more costly. However, the demand for food and fibre will increase, and some increase in their cost relative to other commodities is inevitable. Such increases will justify further expenditure on water conservation.

One of the most important trends in recent years in the construction of large storages has been the increasing use of earth- and rock-fill dams rather than concrete or masonry structures. This trend has been due to a better understanding of soil mechanics, of the permeabilities obtained and the hydro-static pressures induced in such embankments. The development of very large earth-moving equipment has also played a vital part.

The relative value of storages of different sizes and at different locations on any particular catchment can be assessed from statistical analyses of rainfall and stream gauging records coupled with estimates of probable cost, per acre foot of water stored, of construction at any particular site. Once one or more storages have been built on a catchment, the best method of integrating the water of these storages and of distributing the available water has to be determined. The available data can be subjected to statistical treatment, and here the use of modern electronic computers has

proved very valuable. More use will probably be made of these computers in the future, as we learn to pose the questions in a form that they can answer.

Small storages

There has been a very great development in small storages for farm water supply purposes in recent years. In certain environments run-off can be collected from a small catchment, and used on part of the area for irrigation; the name water harvesting has been used in some areas to describe this principle.

Such a system depends on collecting the run-off from a farm, as well as any road drainage and storm water that may penetrate the boundary fence. The run-off is trapped by contour drains and run into dams, the locations of which have been chosen for economy of storage.

Dams may be of the gully type in undulating country, or of the turkey-nest type in flat country. The latter are usually sited alongside an intermittent stream, are fully enclosed and thus receive no run-off. They are filled by pumping in periods of heavy rainfall and consequent stream flow.

Economic storage depends on a high storage : excavation ratio, and both types of dams can give a storage of five or six cubic yards of water for every cubic yard of excavation if they are properly designed.

The water so stored can then be used on a portion of the farm for intensive irrigation, and even in some comparatively high rainfall zones, the use of supplemental irrigation has been found to be very profitable.

Evaporation control

Losses by evaporation from storages throughout Australia are considerable. Much of our pastoral land lies in regions where evaporation from a free water surface exceeds six feet a year, and annual losses of eight feet a year are by no means rare.

A fairly recent process developed by W. W. Mansfield has provided pastoralists and farmers with a simple method of cutting these enormous losses from small storages by at least a quarter.

The method involves spreading a monomolecular film of hexadecanol, a long-chain polar compound which is a pure form of cetyl alcohol, over the surface of small dams. The film is continuously renewed as required from beads of hexadecanol housed in a small raft with gauze windows, which is kept anchored in position on the water surface. The beads are renewed as the material is used up.

Because of its enormous potential significance, details of the Mansfield process were released at an early stage in its development. This has allowed more experience to be accumulated under different conditions throughout Australia, and widespread use on thousands of dams has confirmed its potential value.

Of course there are certain conditions and specifications which must be fulfilled if the method is to be successful, but these are now well known and practicable on areas of water up to two acres in extent.

More recently Mansfield and his co-workers have developed a new technique for controlling evaporation on larger water areas. The hexadecanol is dissolved in a petroleum solvent, and is distributed over the surface from dispensers on the banks. This solution process is not suitable for small dams, as it require fairly close supervision. Also wind is not nearly as effective in spreading water over small areas of water as it is over large areas, so the method is applicable only to areas greater than 100 acres in extent.

Although practical difficulties have arisen, there are now two techniques to reduce evaporation; the raft process for small dams and the solution process for larger water storages.

Seepage control

Water is lost from farm storages and from irrigation channels not only by evaporation but also by seepage into the soil, and as the

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latter is often the greater loss, the problem has received attention both in Australia and overseas.

Although concrete linings are still the standard and many improvements in technique have been made they are still very costly; also experience is showing that they have a limited life, and require large-scale renovation after twenty or thirty years. On the other hand earth linings, particularly if attention has been paid to selection and compaction of earth materials with a wide range of particle size, will last indefinitely, and can actually show a decrease in permeability over the years. Here again modern knowledge of soil mechanics has proved very helpful.

Other linings lower in cost than concrete have received attention in recent years. Bituminous membranes have been widely used, advances in the chemistry of bitumen having enabled the development of materials with suitable physical properties for this purpose. Impermeable clay materials such as bentonite, and the modern development of plastic films have provided other materials for use as linings.

Underground storage

Water below the ground surface is an integral part of the hydrologic cycle, and although it has been receiving an increasing amount of attention in recent years, it will receive considerably more in the future, particularly in Australia.

So far, comparatively little attention has been paid to groundwater resources. Certainly artesian sources have been tapped, notably the Great Artesian Basin of inland Australia, which is the largest of its kind in the world. It has made stock-raising possible in vast areas which could not otherwise have been settled to any extent, but this artesian water is generally too saline for irrigation. There are also projects, notably in Queensland, using groundwater for irrigation, but these are comparatively minor in extent. However, we are still a long way behind such states as California, where approximately 50 per cent. of the water used is pumped from underground.

Ground-water hydrology has been studied in many of our irrigation areas rather from the aspect of getting rid of excess water than its utilisation. The advent of irrigation radically alters an existing hydrologic cycle. In such areas we generally have a system which has reached equilibrium in a climate having somewhere between 10 and 20 inches of rainfall. We then add an extra 12 to 36 inches of water to this system every year, and consequently must expect an entirely different hydrologic equilibrium to be reached. New ground-water systems may be developed, or existing water tables may rise, bringing with them dissolved salts which cause soil deterioration. As we cause these changes, we must be prepared to deal with their effects when these effects upset our agricultural practices, and a great deal of progress has been made in the reclamation of such areas.

In the wider application, surface aspects of hydrology as represented by records of river gaugings and surface storage have been a primary concern in Australia, and Australian climatology is also on a reasonably sound basis. On the other hand the ground-water aspect of hydrology has not been so well developed. The compilation and dissemination of existing data have been commenced, but much more remains to be done. The final step will be the detailed and painstaking investigation of our ground-water resources and of the uses that can be made of them.

WATER RECOVERY

Rain making

Rain-making research in Australia began in 1946, and it was soon demonstrated that certain types of cloud could be induced to rain by seeding them with dry ice. It was realised

from the outset that the most likely method of arriving at a practical answer in a short time was to study the basic physics of natural rain formation. Simultaneously, experiments were designed to obtain a clear understanding of the physical processes which follow introduction of different materials into clouds. This approach quickly brought the Australian workers to the forefront of research in their field. It is interesting to note that workers in America, after an expensive excursion into commercial rain-making are now making a similar approach to the problem.

Rain occurs naturally by one of two quite separate physical processes: by ice crystal formation in super-cooled clouds, or by the coalescence of water droplets in clouds which are warmer than freezing. It has been established that certain minute dust-like particles in the atmosphere (nuclei) play a vital part in initiating both types of rain, and that by supplying appropriate substances when naturally occurring nuclei are absent, rain may be induced artificially.

Work is now being concentrated in two main fields; firstly on the nature and occurrence of "freezing nuclei", and secondly on large-scale field experiments using artificial freezing nuclei.

Further studies of the occurrence of freezing nuclei in super-cooled cloud have confirmed that their concentration tends to vary simultaneously at widely separate localities. Improved freezing nucleus counters have been installed at four Australian sites, and Australia has supplied this type of equipment to other interested groups in England, North America, The Hawaiian Islands and New Zealand.

The results have shown a tendency for the numbers of nuclei to reach a maximum on certain dates close to those predicted by Bowen's theory of meteoritic influence on weather. Similar results were obtained in U.S.A., Germany and South Africa using different equipment.

The discovery that rainfall tends to be heavier on certain days of the year, and that these days occur thirty days after the Earth's passage through the orbits of the known meteor streams, led to the formulation of this Australian theory of meteoritic influence on weather.

The experimental programme in the artificial formation of rain covers three phases: attempts to stimulate rain over large areas, seeding of individual clouds and more detailed investigations into the processes involved.

Large-scale cloud seeding experiments, with adequate controls so that results can be statistically assessed, have been carried out in a number of regions including the Snowy Mountains Area, two areas each of 1,000 square miles in South Australia, and also the New England area of New South Wales. Crystals of silver iodide were used in these experiments, as these have proved to be the most effective artificial freezing nuclei yet discovered.

In the Snowy Mountains experiment there has been more rain on the seeded areas during the periods of operation than would have been expected judging by the rainfall in the adjacent control area. The probable magnitude of the increase is 15 per cent. and the statistical significance of the results has increased as the experiment progressed.

A theoretical treatment of the nucleation process has led to an understanding of the effect of the size of the particles upon their ability to produce ice crystals under given conditions, and thus to a specification of the most desirable size of silver iodide particles for use in cloud seeding. The use of lead iodide is also being investigated, and radioactive tracing methods are being used to study cloud structure and mass air movements.

Rainfall at a critical time or place could result in a disproportionate increase in, say, the production of wheat. For example, it has been demonstrated that the yield of wheat in the Victorian Mallee is closely correlated with the August-September rainfall, to the extent that each additional half inch of rainfall during that critical period results in the production of an extra £1 million worth of wheat. It is in such situations as this that rain-making may,

in due course, prove extremely profitable. The results obtained so far are sufficiently promising to justify hopes of further progress in the future.

The stakes are high and even limited success might prove an enormous economic benefit to the nation.

Water desalinisation

Conversion of saline water to fresh is in its infancy in this country. The main hurdle yet to be overcome both here and overseas is one of cost. Very many methods of conversion have been devised, but all are far too expensive for irrigation projects. Some are just economically possible in situations where domestic, industrial or stock water is at a premium, but even these are on a small scale as yet. The desalinisation does not have to be complete; the salt content only has to be reduced to a figure which stock can tolerate, and so various systems of blending of treated water with water of higher salinity are possible.

IRRIGATION

The importance of irrigation is being realised more and more every year, as our efforts to increase primary production are being intensified. Perhaps the greatest change in our thinking in recent years has been that irrigation is now recognised as economic in areas of comparatively high rainfall. Such areas may only need irrigation for two months in the summer, but these two months are critical. For instance, if fodder or pasture production can be maintained at a higher level for these two months, then this greatly increases the stock carrying capacity not only for these two months but for the whole year.

There has also been an enormous increase in the irrigation of such crops as sugar cane, tobacco, fruit crops and potatoes. The proportion of the area under these crops being irrigated has steadily increased.

Irrigation equipment

Much of this so-called supplemental irrigation occurs on properties where dams have been constructed for the purpose, where small creeks can be diverted, or where underground water can be tapped.

Technological advances in irrigation equipment have kept pace with this trend. We now have special pumps for low lifts, multi-stage pumps for use in deep wells, special portable piping capable of being moved with a tractor or light enough to be set up by hand, quick-acting couplings, plastic piping with rapid sealing joints, and a host of other improvements which have both improved sprinkler irrigation methods and made them relatively cheaper.

Irrigation projects

As well as the construction of storages and distributary systems, governments have another major interest in irrigation projects, as these have been used widely for war service land settlement. Earlier experience had shown that success in such projects depends largely on the selection of land suitable for the intended production, and here modern soil survey techniques have proved invaluable. In fact, the first soil surveys in Australia were carried out thirty years ago in irrigation districts, and no new irrigation project nowadays is commenced without their aid.

Efficiency of distribution

Apart from pipe-lines, which of course keep distribution losses to a minimum, a great deal of work has been done on improving distribution systems. Impermeable linings have already been discussed; another factor is the measurement of water. It is now generally agreed that water measurement is an essential part of any efficient irrigation distribution system, but rather surprisingly, the accurate measurement of comparatively large flows of water is not a simple procedure. A water

meter for use in the field must be accurate, robust and reasonable in cost. It must be an integrating type, in that it must record continuously the quantity of water passing through, and must operate on the minimum loss of hydraulic head. Meters which will fulfil these requirements in most conditions have long been known, but for some conditions special types have still to be developed.

Perhaps the most spectacular development in recent years in the field of water distribution has been the chemical control of water weeds. The impact of this programme has been felt in all Australian irrigation areas, and at the present time methods for the economic control of all aquatic weed species of any importance are either known or in sight. Special mechanised spray equipment has been developed for the purpose. These water weeds can almost block an unlined irrigation or drainage channel; they always reduce capacity and increase losses, and the fact that they can now be controlled has revolutionised water distribution. Operation and maintenance of irrigation systems is now greatly simplified, and it would be true to say that Australia is now in the fore-front of world knowledge on this subject.

Infiltration

An understanding of the infiltration rate or the rate at which a soil will absorb water is vital to the selection of correct irrigation techniques. With this must be combined a knowledge of fluid mechanics of surface irrigation on the one hand, and of the hydraulic characteristics of irrigation equipment if sprinkler irrigation is to be used.

The emphasis is now on investigations to determine the most efficient methods of applying water to irrigated land, the objective being to obtain maximum production per acre foot of water used, as opposed to the usual aim of obtaining maximum production per acre. Advances have been made in Australia on the theoretical treatment of these problems, but there remains quite a lot of investigation on the practical application in the field.

Conservation or irrigated land

Water influences soil conservation in several ways. Good soil conservation generally means optimum water conservation, but unwise land use can lead to soil erosion, which may be accompanied by water-logging and salting of part of the landscape. In this work progress has been much greater in recent years following the use of the ecological approach to conservation. We now try to understand the causes of soil deterioration due to changes in environment induced by man. This is followed by planning of conservation programmes for farms, for subsidiary catchments and finally for whole catchments.

The amount of water applied by irrigation is also critical. If the optimum amount is applied then production will be at a maximum, but excess water will again cause water-logging and salting. The place of groundwater in the hydrologic cycle has already been discussed. When soil deteriorates by the rise of soluble salts to the surface following waterlogging, ways must be found to reclaim this land.

The most economical way to prevent waterlogging is by surface drainage, and in Australia a great deal of work has been done on this method. Techniques have been developed in the last twenty-five years and a large area of salty land has been reclaimed. The method used is a combination of good land preparation, good irrigation technique and good surface drainage. It has been developed mainly on pasture land, and it has been found possible to control the shallow water tables involved by correct surface irrigation if the vegetative cover can be maintained. An adequate supply of irrigation water is essential, and in many of the early irrigation projects where salting had taken place, reclamation has been carried out to the limit of the water available.

If these methods are not suitable, then subsurface drainage must be used. This may consist of a grid of mole or agricultural tile drains, or may involve pumping of groundwater. Either method is expensive, and as a general rule can only be used where high value crops are being produced.

Mole drainage has been successful in some cases on pasture land, but it can only be used on fine-textured soils of sufficient slope. On

the other hand tile drainage has been widely used in horticultural areas. In the first instance, some twenty-five years ago, the depth and spacing of drains to be used on many of the soil types needing tile drainage were worked out experimentally and gradually a successful technique was evolved. More recently a mathematical approach has placed this subject on a sounder basis. Australian workers, following leads from overseas, worked first on ideal cases and sought mathematical solutions, which were then tested experimentally by the use of electrical analogues, designed to simulate flow conditions through porous media by the construction of electrical circuits. Finally, of course, the resultant recommendations had to be tested in the field. This approach has been used with marked success in some irrigation districts in Australia.

CONCLUSION

Our knowledge of soil and water relationships in the field of water use has come a long way in the last twenty-five years, and is now such that we should be able to achieve our objective — a form of land use which shall be permanent as well as productive.

There is no doubt that there are still gaps in our knowledge, and there is a need for vigorous research programmes. There is also need, however, for an equally vigorous agricultural extension programme, and what is probably more important, for a forward-looking financial and economic policy which will provide an impetus to encourage good land use, and so preserve for all time our irrigation projects and our soil.

AGRICULTURAL SCIENCE
IN AUSTRALIA 1935-1960

AGRICULTURAL ECONOMICS

K. O. CAMPBELL

In an article in the *New York Times* of November 8 last year, Arnold Toynbee discussed the intriguing question as to whether it is great men or impersonal forces which predominantly shape the course of history. He concluded that the more illuminating approach is to think of history in terms of an interplay between forces and personalities.

Looking at the development of agricultural economics in Australia during the past quarter century, one is impressed by the pertinence of Toynebee's interpretation. There have been dominating personalities—men like Sir Samuel Wadham and Sir John Crawford — each of whom, in his own way, has helped to shape the development of the field and in so doing has left an indelible mark on the profession. But the peculiarities of the Australian environment and local traditions and attitudes have played no less important a role, as have two world-shaking events, the Great Depression and the Second World War.

The history of agricultural economics in Australia has been inextricably bound up with public administration with respect to agriculture. Whether this close affiliation with government has helped or hindered the development of this field is a moot point. I would argue from the standpoint of the development of the formal discipline that the drawbacks of this symbiotic relationship have outweighed its advantages. But, as a question of fact, it cannot be denied. Some of the key personalities have had as much, if not more, impact on agricultural administration and policy as they have had on the development of the discipline of agricultural economics. In the circumstances it would be fruitless, and indeed misleading to attempt to confine a survey such as this to agricultural economics in any formal sense. At the same time the close nexus between agricultural economics and government policy in this country means that the stages of its development are intimately related to the economic and agricultural history of the period.

To survey the development of agricultural economics during the past twenty-five years, is virtually to cover the entire history of the subject in Australia. Even though, in world perspective, rural economics was a relative latecomer to the agricultural sciences' club, its appearance in this country was even more delayed. Formal research units were to be found in the United States as early as 1902, in the United Kingdom from 1913, in South Africa from 1925 and in New Zealand from 1926. Yet the first comparable Australian unit did not appear until 1941.

THE PRE-WAR PERIOD

In 1935 the Australian economy was still emerging from the throes of the Great Depression. The Royal Commission on the Wheat Industry was still in process of completing its work. As an aftermath of the ill-advised agricultural expansion of the twenties, the various states were setting about the reconstruction of the so-called marginal areas. Problems of agricultural surpluses and economic nationalism had given rise to an increasing awareness of the fact that overseas markets were not unlimited. The responsibilities of the Department of Commerce in this direction were expanding. This was also a period of great uncertainty regarding the constitutionality of organised marketing schemes.

In May, 1935, the first meetings of the Australian Agricultural Council and its civil service counterpart, the Standing Committee on Agriculture, were held. The establishment of the Council was an expression of the acknowledged need to adopt a common approach to marketing problems.

This was also a time of ferment concerning matters of general economic policy affecting rural industries. February 1936 saw the appointment of the Royal Commission on Money and Banking, which *inter alia* was to consider the adequacy of rural credit facilities.

All these facets of the agricultural scene offered scope for economic research. Yet there was no formal institutionalised research in agricultural economics under way. One side effect of the Royal Commission on Money and Banking was to stir some of the banks into establishing economic departments, and some of these did interest themselves in rural problems. The most notable of these were probably those established by the Rural Bank of N.S.W. and the Bank of New South Wales. Some of the work done in the Queensland Bureau of Industry under the direction of Colin Clark also had important agricultural implications.

But the most conspicuous deficiency of the thirties was the lack of any serious attempt to provide training in agricultural economics at the universities. By the late thirties at the University of Sydney some attempt was being made to give the economics courses required of agricultural students some agricultural bias, and the Melbourne curriculum contained quite a deal of material on marketing and economics. But in neither case did the courses cover the field of farm management nor were they intended as preparation for a professional career in the field. The position as regards training at other universities was even less adequate. On the research side, some work on the costs of tractor operation was initiated at the University of Western Australia in 1938 and in the same year a land-use survey was undertaken at the University of Melbourne.

The inadequacies of training in agricultural economics in the Australian universities in this period were to become abundantly clear when key personnel were required to help meet the problems of war and reconstruction. Indeed, the legacies of that period in the form of inadequately trained personnel are still a millstone today. The shortage of properly trained personnel tempted various agricultural scientists, who were competent workers in their own fields, to become "amateur" economists. This did not help to raise the stature of the new discipline, or to facilitate the acceptance of the research product of agricultural economists by discriminating economists or indeed by some departments of government.

THE EARLY WAR YEARS

The years 1940 and 1941 was a time of considerable agitation concerning the future of agricultural economics in this country and in this the Australian Institute of Agricultural Science and its individual members played significant roles. There are interesting parallels between these two years and the previous high point of pressure for the initiation of agricultural economics research in Australia, viz. 1928-29. Just as the advent of the Depression halted progress in 1930 so the attack on Pearl Harbour on December 7, 1941, and the resulting intensification of Australia's wartime commitments, dashed any hope of early fulfilment of the aspirations of the protagonists

of the new discipline. Indeed, had it not been for the particular conjuncture of the Great Depression and the Second World War, it is safe to predict that the rate of development of agricultural economics in the Australian Commonwealth would have been vastly different.

Probably the major effort during this period centred around the proposal to establish a so-called Institute of Agricultural Economics. The original promoters of this plan were a group at the Veterinary School at the University of Sydney (Ian Clunies Ross, H. R. Carne, R. M. C. Gunn and D. A. Gill), together with L. C. Holmes of the Bank of New South Wales. To aid in the implementation of their plan, this group accepted the invitation of the Australian National Research Council (of which Carne was secretary), to reconstitute themselves as a subcommittee of the Council. Professor Eric Ashby, the chairman of the Council, and Professor Clunies Ross subsequently presented the proposal to the Standing Committee on Agriculture in January, 1941. The Australian Agricultural Council in turn decided to take no action.

The reasons for this decision are not recorded. However it would seem that the principal cause of failure was that the advocates of the proposal, in their desire to ensure that the institute was in a position to carry out objective research completely free from political interference, put forward a rigid administrative structure which was quite unpalatable to administrators and their political masters.

The A.N.R.C. subsequently approached the executive of the Council for Scientific and Industrial Research with a proposal that the C.S.I.R. should establish a unit within its organisation to conduct research in agricultural economics. Professor Ashby, who undertook these negotiations, reported back to his executive: "It was clear that C.S.I.R. itself is not prepared to initiate research on agricultural economics nor is the Council prepared to suggest that any other government department should do so." The A.N.R.C. then decided that a similar approach should be made to the "Department of Reconstruction", but there is no indication of the response obtained.

This was not the first, nor the last time, that a proposal of this kind was put to the C.S.I.R. executive. For instance, a similar recommendation came from the C.S.I.R. State Committee in Western Australia in December, 1942. The executive throughout seems to have adhered to the attitude, made explicit by the British Economic Mission in 1929, that "the work of the C.S.I.R. should not be prejudiced in any way by association with an economics research unit". While the view was constantly reiterated in the early documents that any research unit should "be placed entirely outside the sphere of political influence," the C.S.I.R. apparently did not then feel that its own scientific reputation was sufficiently secure to run the risk of providing the protection needed for a fledgling unit engaged in research in the rural social sciences. The irony of fate determined that it was not social science research but activities in the physical sciences which in 1948 were to bring the C.S.I.R. into political controversy, threaten its independence and result in its being brought under Ministerial control.

One point which was repeatedly brought forward at this time as an obstacle to the implementation of the A.N.R.C. and other proposals was the lack of suitably trained men to undertake the research envisaged. The A.N.R.C. with the willing cooperation of the Vice-Chancellors of the Australian universities therefore proceeded to call a conference at Melbourne University on July 24 and 25, 1941, to discuss the training of agricultural economists. This conference, which was attended by representatives of all the universities, agreed that there was "urgent need for the provision of facilities for training and research in agricultural economics at Australian Universities". The A.N.R.C. proposal before the conference was for the establishment of post-graduate training centres at Sydney and Melbourne, but this was modified at the conference to a recommendation that a single centre be set up at Melbourne or Adelaide. There was some measure of disagreement among the university representatives as to the wisdom of centralising most of the training in a single institution.

The proposals of the conference were transmitted to the Australian Vice-Chancellors' Committee, which met three weeks later. That Committee endorsed the general resolution quoted above and delegated the Vice-Chancellors of Sydney and Melbourne Universities to take up with the Government the problem of finance. At the next meeting, a year later, these gentlemen were requested to make further enquiries. Apparently, the inadequacy of the financial assistance offered and the deteriorating war situation led to the indefinite postponement of the scheme.

Though the A.N.R.C. subcommittee on agricultural economics did not achieve any of its immediate goals, it would seem to have been instrumental in stirring up widespread interest in the subject. Several subsequent developments can be traced back indirectly to its efforts. One was the decision in June 1941 to establish a Division of Agricultural Economics in the N.S.W. Department of Agriculture. The first four appointments to the Division were made in October of that year. J. G. Crawford, then economist to the Rural Bank, who had been acting as Economic Adviser to the Department of Agriculture since the previous March, assumed responsibility also for the oversight of the work of the new Division.

In the early work of the Division considerable emphasis was placed on land-use surveys, a matter which had for some time been receiving attention from several branches of the Australian Institute of Agricultural Science. However, the advent of Pearl Harbour, two months after the Division's establishment, led to a radical alteration in its immediate research activities. In 1943 a record-keeping service for farmers was initiated, only to be discontinued about two years later. The Division was amalgamated with the Division of Marketing in September 1943. The only other State Department of Agriculture to show any interest in initiating work in agricultural economics at this period was the Western Australian Department, but the single position established there in 1942 was regarded primarily as an advisory rather than a research position.

Professor K. O. Campbell is Professor of Agricultural Economics at the University of Sydney. When appointed to this position in 1956 he was the first Professor of Agricultural Economics in Australia. In 1952 Dr. Campbell was President of the New South Wales Branch of the Institute.

A second effect of the A.N.R.C. proposal was to spur the A.C.T. Branch of the Institute in April, 1941, to prepare a memorandum on agricultural economics. Bearing in mind objections to the earlier A.N.R.C. submission, the A.C.T. committee put forward its suggestions in a more tentative form, but pressed for an organisation which would be "a research or fact-finding body and a Government Department" and suggested that this "could probably best be set up as a Division of the C.S.I.R.". As a consequence, the Branch recommended that "the Australian Institute of Agricultural Science should strongly advocate the immediate establishment of an organisation to undertake research in agricultural economics". Discussions in the Federal Council of the Institute were prolonged. At a meeting on December 8, seven months later and a few hours after the attack on Pearl Harbour, the Council reported that "the time was still inopportune for a vote to be taken on the original motion of the A.C.T. Branch". In the meantime, however, some of the other branches of the Institute were prompted to give detailed consideration to the general question and the A.C.T. branch felt impelled to prepare a second memorandum, in which it was mainly concerned to answer questions raised concerning political independence and the shortage of personnel.

A third indirect outcome of the A.N.R.C. discussion of the shortage of trained personnel (and also, in part, a reflection of the immediate staff needs of the new Division in the N.S.W. Department of Agriculture) was the initiation of a fifth-year (essentially a post-graduate) course in agricultural economics for agriculture students at the University of Sydney in 1942. However, although the three departmental trainees who undertook this special

training all obtained honours, the Department subsequently appointed only one of them to the Division of Agricultural Economics.

FEDERAL INTERVENTION IN AGRICULTURE

The Japanese attack on Pearl Harbour inevitably becomes the turning point in any historical discussion of Australian agriculture during World War II. In the present context, as has been indicated, Pearl Harbour meant the frustration of any hope of the early establishment of an organisation to conduct research in agricultural economics. But, on the other hand, it presaged the growth of a federal agricultural bureaucracy, which was eventually to prepare the ground for the establishment of the Bureau of Agricultural Economics.

The germ of what was to become the B.A.E. was probably the Rural Industries Division in the Department of War Organisation of Industry. At the end of 1941 Crawford, who was later to become the first Director of the B.A.E., was seconded from the Rural Bank of N.S.W. to direct that division on a part-time basis and he was joined by a number of economists and agricultural scientists. In the early months the Division was preoccupied with the task of helping to establish manpower priorities, but work on production goals and materials supply for the Production Executive of Cabinet, the Australian Food Council and similar interdepartmental committees, was soon to dominate its activities.

Towards the end of 1942 and in early 1943, the work and responsibilities of the former Department of Commerce were greatly expanded. A Director-General of Agriculture was appointed. The secretary of the Department became executive head of a new body known as Commonwealth Food Control and the responsible minister became Minister for Commerce and Agriculture. This was, in fact, the first explicit recognition of the need for agricultural administration at the federal level. Though several branches of the Institute of Agricultural Science, especially the N.S.W. branch, played some role in agitating that the Commonwealth Government should accept responsibilities in this area, it was probably the pressure of events combined with the influence of individual members within the federal service which led to the ultimate achievement of that goal. The work and witness of the agricultural economists and scientists who were assembled and served in the Commonwealth Government during the war (often in temporary capacities) undoubtedly helped to convince politicians and others that the specialised economic and technical advice thus available was also likely to prove invaluable under peacetime conditions. At least, the general form of the administrative machine established in wartime was retained at the cessation of hostilities.

But there was another wartime instrumentality which was destined to affect the future of agricultural economics in the Commonwealth Government. This was the Department of Post-War Reconstruction, which was established in December 1942. The fact that Dr. H. C. Coombs, who had long been interested in promoting work in agricultural economics, was appointed Director-General of this department, doubtless helped so far as the rural side of its activities was concerned. J. G. Crawford moved from the Department of War Organisation of Industry to become Director of Research in the new department, while still retaining his post at the Rural Bank of N.S.W.

The early work of the rural section of the Research Division, which was later to become the Rural Research Division, was largely given over to providing secretarial and research facilities for the Rural Reconstruction Commission after its appointment in February 1943. The work of the Commission, on which Professor Wadham sat as one of the Commissioners, did much to stimulate public interest in the economic aspects of agriculture, and the Commission's ten reports, which appeared intermittently from January 1944 to June 1946, dealt authoritatively with many of the issues which advocates in earlier years had suggested should be the concern of a division of agricultural economics. The Commission fully realised that its work was of a preliminary nature and in its final report urged generous Commonwealth support for the research activities of the permanent Bureau of Agricultural Economics, which had actually come into existence before the Commission's work was done.

One matter to which the Commission gave early attention was the question of land settlement for returning ex-servicemen. The more detailed work of devising specific machinery for carrying through this operation in the light of constitutional difficulties, and the assessment of long-term market prospects as a basis for sound settlement, was undertaken in the Rural Research Division of the Department of Post-War Reconstruction. As a minor part of this activity, it is of interest to note that the first Australian-orientated textbook on farm management and agricultural economics was prepared by members of the staff of the N.S.W. Division of Marketing and Agricultural Economics for use in the rural training schools for ex-servicemen.

There is evidence that as early as September 1944, intra-departmental recommendations were being made to the Minister of Post-War Reconstruction for the establishment of a Bureau or Division of Agricultural Economics, whose primary responsibilities were to be the examination of land settlement proposals and post-war market prospects. It is also clear that suggestions that such an authority should be autonomous and independent (i.e., analogous to the Tariff Board) had not been well received, and that therefore the proposals recommended the establishment of the Division within the regular departmental structure, save that the Director was to have the right to advise the Minister directly. Following inter-departmental discussions, the Minister of Post-War Reconstruction and the Minister of Commerce and Agriculture jointly submitted a proposal to Cabinet that a Division of Agricultural Economics be established, based on the Rural Research Division in the Ministry of Post-War Reconstruction. The Division formally came into existence in July 1945, with an understanding that it would undertake certain tasks for the Department of Commerce and Agriculture, and that it would eventually be transferred to that Department. In the meantime, the Division had been strengthened in April 1945 by its absorption of the Rural Industries Division of the Department of War Organisation of Industry.

The Bureau's strength was increased considerably during the first twelve months of its existence and by the time it was transferred to the Department of Commerce and Agriculture on July 1, 1946, it had a staff of 21. (It continued to be housed with the Department of Post-War Reconstruction until early in 1950.) On his permanent appointment as Director, Crawford resigned from the Rural Bank of N.S.W. By the time of its transfer, the Bureau was beginning to become involved in another responsibility which was to assume considerable importance in its early years, the determination of production costs. This stemmed from the work which it did for the Simpson committee on wheat costs and for the Joint Dairy Industry Advisory Committee.

Perhaps the most significant fact from the standpoint of the long struggle to secure a Bureau of Agricultural Economics is that ultimately the main grounds for its establishment were not basically research-oriented, but were almost entirely related to an immediate administrative responsibility, the settlement of ex-servicemen on the land. In the words of the then Prime Minister in a letter to State Premiers, war service land settlement was "the reason which precipitated the decision". Probably most would agree that the end justified the means. But, whether the circumstances of its establishment are in part responsible or not, the fact remains that it has been difficult in subsequent years to shift the emphasis in the Bureau's work away from administrative and governmental advisory work towards more fundamental research. The contrast with the Division of Marketing and Agricultural Economics in the N.S.W. Department of Agriculture, in this regard, is striking.

AGRICULTURAL ECONOMICS IN THE UNIVERSITIES

The intensification of the war effort after 1941 and the commitment of manpower and resources to immediate tasks naturally produced a virtual hiatus so far as the development of agricultural economics in the universities was concerned. However, the rural sociological investigations centred on the Melbourne School of Agriculture (which had commenced in 1941), and the rural economic surveys conducted by the staff of the Institute of Agricul-

ture at the University of Western Australia, were continued throughout the war. Such instruction in agricultural economics as was given students in Australian universities continued to be provided on the same inadequate basis as before.

Around 1943, a group of people from Sydney and Armidale began to discuss proposals that research and teaching in rural subjects should be initiated at the New England University College. The early discussions proceeded largely in terms of rural economy, in the sense of crop and animal husbandry. By 1944, the proposals began to be directed more specifically to training and research in rural economics. In 1946, a more detailed plan for the establishment of a Faculty of Agricultural Economics was published for wider circulation.

Also in 1946, no doubt as a result of the efforts of the Principal, A. R. Callaghan, a position for an agricultural economist was created at Roseworthy Agricultural College and D. B. Williams was appointed. At that time, in addition to teaching diploma students, he was responsible for lectures to students from the University of Adelaide.

In September 1948, the Commonwealth Bank of Australia advised the Senate of the University of Sydney that, subject to its acceptance, the Bank proposed to make grants up to a total of £50,000 from its Rural Credits Development Fund for the purpose of endowing and helping to maintain a Chair of Agricultural Economics at that university. The Senate accepted the offer and resolved to establish the Chair in the Faculty of Agriculture. However, this position, which became the first permanent academic appointment specifically in the field of agricultural economics in Australia, was not filled until August 1951.

In 1950, the University of Western Australia secured financial assistance from the Rural Credits Development Fund to create a position of Research Fellow in Farm Management for a period of years, a post to which H. P. Schapper was duly appointed in 1951. In 1956, a special grant of £15,000 was obtained from the same source, to establish the permanent position of Reader in Agricultural Economics.

In 1953, F. G. Jarrett, who had received post-graduate training in agricultural economics, was appointed Lecturer in Economic Statistics at the University of Adelaide. However, it was not until 1956, following a change in curriculum, that he began to assume major responsibilities for teaching agricultural economics.

When the University of New England achieved its autonomy in 1954, the act of incorporation envisaged the establishment of Faculties of Rural Science and Agricultural Economics. Plans for the latter faculty were made, but finance was lacking. In 1956, consequent upon a successful application to the Commonwealth Bank for £20,000 to enable the first two appointments to be made, the Council of the University decided to establish the Faculty. Professor J. N. Lewis was appointed to the Chair of Agricultural Economics early in 1957.

For many years, from within the various Australian universities, recommendations for the establishment of permanent academic positions in agricultural economics went forward periodically to university administrators, but were not successful in competition with other claims. Rising student populations and deteriorating financial situations militated against expansion into new fields of endeavour. It is significant that, in the case of all three universities where appointments in agricultural economics were made prior to 1957 (excepting Adelaide where transmutation occurred), the appointments were only achieved as a result of specific external financial assistance and that, in the case of the first, the University of Sydney, the initiative lay outside the University. Without the generous aid from the Rural Credits Development Fund of the Commonwealth Bank, agricultural economics would not have progressed as far as it has in the Australian universities. But whether the receipt of outside support is always an auspicious basis for future growth in an academic environment is another question.

That overall stringency of finance was the key reason for the limited growth of agricultural economics as a university discipline in the decade after the war, is confirmed by the

change which occurred after the governments had accepted the recommendations of the Murray Committee on Australian Universities in 1957. In the meantime, several universities had managed to expand research activities by making some short-term appointments financed by outside grants.

With the increased funds made available to the universities in 1958, the way was opened for further appointments in agricultural economics. In 1958-59, initial permanent positions were created at the University of Queensland (where a part-time lecturer had been appointed in 1958) and the University of Melbourne, a post of research fellow was created at the Australian National University, and additional permanent positions were authorised at the Universities of Sydney, Western Australia and New England. In 1960, Canberra University College made a first appointment, and an increase in establishment was mooted in Adelaide. The unfortunate consequences of rapid intermittent growth, in the form of an insufficiency of adequately trained and experienced agricultural economists, were again evident, as they had been in the Bureau of Agricultural Economics in its earlier years. More steady and gradual growth would have been far sounder from a long-run point of view. Nevertheless, in 1960 we are in the position that, in all the mainland states and the Australian Capital Territory, there is at least one academic agricultural economist.

After World War II, the flow of Australian post-graduate students to American and, to a lesser extent, British institutions for training in agricultural economics steadily increased. Though, following the traditional pattern, some of these never returned to their country of origin, and though one could wish for greater diversity in the institutions chosen for overseas training (Harvard, Chicago, Iowa and Illinois are the principal universities represented), there is no doubt that Australian agricultural economics has benefited thereby. Some New Zealanders with overseas experience have also been attracted to the Australian profession. The greatest cause for regret, in view of the fact that the absolute numbers involved were never great, is that so large a proportion of the men and women who invested in advanced training overseas have left the profession, subsequent to their return to this country. The root cause of the trouble would appear to be the status of agricultural economics research in the Commonwealth Public Service.

AGRICULTURAL ECONOMICS IN THE GOVERNMENT SERVICE IN THE POST-WAR PERIOD

Apart from the N.S.W. Department interest in agricultural economics in Australian State Departments of Agriculture has been very circumscribed. To some extent, this may reflect the deterioration of state government finances generally *vis-a-vis* the Commonwealth and the difficulty of recruiting trained professional personnel given the level of salaries and the limited opportunities for advancement which have prevailed in the state services. But there have been other reasons. For instance, the existence of the Bureau of Agricultural Economics has, in some measure, been used as an excuse for inaction in some states.

Although the N.S.W. Division of Agricultural Economics has never achieved the complement of staff foreshadowed at its establishment (viz. sixteen) and though it has had some personnel problems, its comparatively small group of workers has managed to build up a commendable research record at the same time as it has been fulfilling its role as economic adviser to the administration. Most of the better work has been in the area of production economics and has largely been published since 1950. The results of such research have almost entirely appeared in the Division's own journal, *The Review of Marketing and Agricultural Economics*. Since the Division built up this reputation it is not surprising that heavy inroads have been made on its professional staff in recent years by the Australian universities, which now found themselves able to employ some agricultural economists but had to find them amid a critical shortage of trained personnel. If it had not been for the unconscionable restrictions on transfers to the federal service, it is possible that attrition of the Division's staff may have occurred much earlier.

In the other state departments, the dual role of an economics unit has never been fully accepted. In Western Australia, the policy advisory role has dominated the situation, a second appointment being made about eighteen years after the first. The small units (consisting of one or two persons) established in Victoria in 1954, in South Australia in 1955, and in Tasmania in 1956, have also been conceived in very narrow terms, but in the extreme opposite direction. Their function has been usually understood to be simply that of conducting farm surveys. That administrators should continue to consider themselves adequately qualified to resolve policy problems involving increasingly complex economic issues without specialist advice is amazing, to say the least. Due no doubt to their narrow terms of reference and small size, the departmental units in the other states have never approached the stature of the N.S.W. Division.

In April 1958, an Economics Research Branch was established within the Marketing Division of the Queensland Department of Agriculture, following some economic investigations which the Division undertook in the immediately preceding years. While this new unit has been set up on a somewhat broader base than those in some other states, it is still small and its work to date has been heavily oriented towards field investigations. In Queensland and elsewhere, there has been a great deal of talk about farm management extension and the opportunities for the State Departments of Agriculture in this area. But it has to be realised that at current rates of staffing, they cannot even begin to tackle this important work.

At the federal level, the staff of the Bureau of Agricultural Economics grew rapidly in the early years. Generally speaking, the staff recruited were either economists or agricultural scientists. In few cases did the appointees have dual qualifications, though some have endeavoured subsequently to gain further professional training. By 1950, the approved establishment provided for 84 permanent professional positions. J. G. Crawford left the directorship in that year to become Secretary of the Department of Commerce and Agriculture and he was succeeded by T. H. Strong. The heavy emphasis in the Bureau's work on *ad hoc* investigations with policy implications has meant that limited attention has been given to more fundamental longer-range research problems. Land settlement and production cost investigations gradually diminished in importance after 1950. Except in the case of the Wool Section (which is supported by grants from the Wool Industry Research Fund), the Bureau has been impeded in attempts to give its work a greater research orientation. However. at the present time, there are some encouraging signs of increasing interest in more basic research. The Bureau's *Quarterly Review of Agricultural Economics* together with its periodic commodity outlook statements has helped to bring its work to public attention, but the nature of its activities has necessarily meant that much of the evidence of such activities must lie buried in official files, rather than be published in professional journals.

A major obstacle to the raising of professional standards has been the failure of the Public Service Board to recognise the Bureau as a research organisation and in particular its failure to provide opportunities for advancement to those who wish to make economic research their career. Efforts to right this situation in the mid-fifties through regular arbitration procedures failed partly because of the unwillingness of research administrators in other fields of agricultural science to acknowledge that research workers in agricultural economics with equivalent qualifications should be accorded similar salaries and status to research workers in the fields for which they were responsible. The Bureau, for years, has suffered from rapid staff turnover due to the movement of its personnel (including some of its most experienced and best-trained officers) to more remunerative posts in other departments of government. Perhaps this is to Australia's overall benefit, but it does not help to raise the quantity and quality of Australian research in agricultural economics.

The great pity is that having after a long struggle achieved a Bureau of Agricultural

Economics and having assembled therein the greater part of the professional personnel in Australian agricultural economics, we have the Bureau in an institutional environment where it is apparently unable to do the kind of job which its original advocates envisaged. We have the word of the former Director that the Bureau "is essentially a Public Service agency whose prime function is to service the Department of Primary Industry and the Australian Agricultural Council. . . . Unfortunately, the Bureau is not classed by the Commonwealth Public Service Board as a research organisation. The Board has in fact ordered the elimination of any suggestion of fundamental research in the duties of the Bureau personnel." Advice to governments on issues of economic policy is important and no one would deny that Australian governments are infinitely better off in this regard today than they were twenty years ago. But this should be but one facet of the total research effort.

Having watched the developments in the past two decades, one cannot help but feel that had the C.S.I.R. been willing to accept the Bureau as a research unit within its own organisation at the beginning of the period we are reviewing, agricultural economics research in Australia would be more securely based and of better quality than it is today. There are other institutional arrangements by which the same objectives of independence, objectivity, depth and quality of research could be achieved, but given Australian traditions and practices, the kind of set-up planned in the 1940 era would appear to have advantages over what we got instead. If it is impossible to achieve these goals within the structure of a government department, perhaps we need to revive the proposals of yesteryear or follow the British, American and more recent Canadian pattern of subventions to strengthen university research in this field.

Of course, the view can be advanced that good research can be done irrespective of the institutional environment. But there is reason to believe that this is less true of the civil service than of universities.

THE PRESENT STATUS OF TRAINING AND RESEARCH

The Present Status of Training and Research What can be said of Australian agricultural economics in the year 1960? In terms of the almost complete absence of research and training facilities in 1935, one is disposed to say that great progress has been made. But in terms of research accomplishments, in terms of the meagre resources still devoted to agricultural economics in the State Departments of Agriculture and the universities of the Commonwealth and in terms of the rate of growth of other fields of agricultural research, the observer must needs say that development has scarce begun. That this should be so in a major primary-producing country, given the economic complexities of rural production and marketing in the modern world, remains one of the perplexing questions of our time.

As for training, it can be said that today no agricultural scientist graduates without at least some acquaintance with the economic principles underlying rural production and price formation. At the same time some increased emphasis on farm management at the undergraduate level is greatly to be desired. Facilities are now available at several universities for specialised training in rural economics in the later years of the agricultural science course, and at Sydney (since 1956) and New England (since 1958), it has been possible to secure specialised training in agricultural economics beginning in the first year. A growing number of post-graduate degrees and diplomas are being awarded in the field. The limited number of teaching staff precludes provision of as wide a basis of training as is given in some overseas institutions, but standards compare favourably. Even so, a shortage of qualified agricultural economists still dogs the profession.

Agricultural economics research in Australia, as I pointed out at the beginning of 1957, has predominantly been descriptive rather than analytical. There has been some material improvement since that time as the volume of university-based research has expanded and as the profession has been gradually enriched by better trained personnel. Some first-rate research has been done, but

its quantity and coverage is still distressingly limited. This is particularly evident if one attempts to draw on Australian research results for the purpose of teaching or exposition. A recurring criticism is that what has been done has been largely confined to specific fields of agricultural economics (especially production economics) and that problems in demand and marketing have been comparatively neglected. There are a number of reasons for this bias in the Australian scene but the criticism is still pertinent.

As is naturally to be expected, the nature of research undertaken has been dictated in part by the characteristics of the local environment. In the early period, the determination of production costs, long since dispensed with as a blind alley in most other advanced countries, was undertaken on a wide scale, mainly in response to local political traditions and pressures. In the fifties, the relation of the agricultural sector to the balance of payments in a rapidly developing economy, the nature of the agricultural investment process, the peculiar economic problems associated with investment in pasture improvement, the relation of improved technology and investment to rising productivity, and feed-inventory problems arising from recurring drought are all significant matters which have exercised the minds of Australian research workers. It is reasonable to suppose that these and other studies, as well as influencing local policy in some degree, have made some contribution to the understanding of similar problems in other parts of the world. At the same time Australian research workers have not been backward in making use of newer research techniques that have become available and in pressing the new electronic computers into service in the pursuit of their research objectives.

The extensive nature of Australian agriculture and the limited amount of research resources available have led to the almost complete neglect of intensive continuous farm management studies such as one is wont to find in other countries. While this type of work has been subject to criticism, the fact remains that such detailed studies prove invaluable for farm management extension purposes. Current efforts to increase this latter class of work in Australia are likely to prove of limited effectiveness in the absence of a core of detailed management data.

Recent years have seen some further research conducted in the field of rural sociology, particularly with reference to agricultural extension. It is to be hoped that work in this complementary field can soon be placed on a continuing basis.

The Australian Agricultural Economics Society is destined to play an increasingly important role in influencing the future course of agricultural economics research in this country. The Society was founded in Sydney in February 1957 on a federal basis and there are now branches in Sydney, Melbourne and Canberra. The Society's annual three-day meetings, coupled with its publication of *The Australian Journal of Agricultural Economics,* must help in improving research standards in this country, and help to stimulate wider appreciation of the contribution which agricultural economists can make to Australian agriculture.

But "what's past is prologue". Agricultural economics now has a foothold (albeit a rather precarious one in some cases) in all of the Australian Departments of Agriculture as well as in all the Australian universities except two. However, substantial progress cannot be expected from a series of isolated individuals located hundreds of miles from their professional colleagues. The scale of research activities in these centres needs to be increased.

The challenge in 1960 remains basically the same as twenty years ago—namely, (1) to train more agricultural economists in order to overcome present shortages, to provide for needed expansion, and to improve the general quality of Australian research; and (2) to make provision, both within government and in the universities, for far more, and far more fundamental, research into the economic aspects of the Australian rural industries.

AGRICULTURAL SCIENCE
IN AUSTRALIA 1935-1960

THE AGRICULTURAL SCIENTISTS

H. C. FORSTER

The past 25 years have seen a major advance in primary production in Australia, not only in total production but also in the diversity of new types of crops and pastures and in the improvement of the standard of farming and average production per acre.

Much of this has been due to the initiative and drive of the graziers and farmers themselves, but the agricultural scientists of Australia have also played their role in achieving increased production.

Future expansion of agriculture in this country will be vital if we are to measure up to the challenge of an increase of one hundred per cent. of the population of the world in the next 40 years. There will be many problems to be faced, not only in intensification of production on land already under production, but also in opening up new areas which for one reason or other have not yet been developed.

In his opening address in 1935 our first President, the late Dr. A. E. V. Richardson, said: "The major work of the Institute will be the development of an esprit de corps among the members of the profession throughout the Commonwealth, and in assisting in the formation of a public opinion which will insist that the agricultural and pastoral resources in Australia should be developed by the best known methods and utilised to the best advantage attainable."

We have every confidence that agricultural scientists individually will be ready to continue to play their part, but have we as members of the A.I.A.S. really planned the role of the profession in the future. We may well ask ourselves—Are we attracting sufficient numbers of the right type of men to cope with the demand of the future? Is the training given by our universities designed to meet the need for the wide variety of scientists required? Are the conditions for employment and the facilities for work such that our scientists can play their part? Last but not least, are our government departments, either state or Commonwealth, or our universities, receiving sufficient finance to enable them to cope with their responsibilities?

May we look first at the achievements of our first 25 years and then come back to the challenge of the future.

NUMBERS EMPLOYMENT AND STATUS

From its initiation the Institute has taken considerable interest in the status and employment of its members. Various surveys have been made and the information published from time to time. The latest of such surveys, *Agricultural Scientists in Australia,* is an outstanding contribution of which the Institute can well be proud.

Numbers

A complete record of the whole profession is not available and we must rely on figures for Institute members. As shown in Table 1, there has been an increase of over 450 per cent. in the total number of corporate members of the A.I.A.S. since 1935, the figure for 1959 reaching 1,487. The increase has varied from state to state with Victoria showing the largest increase of 610 per cent. Figure 1 presents in graphical form the numbers of members over the 25 years and shows that if we exclude the abnormal period at the end of World War II, the rate of increase of the membership of the A.I.A.S. and thus of members of the profession, is as high now as at any time in our history.

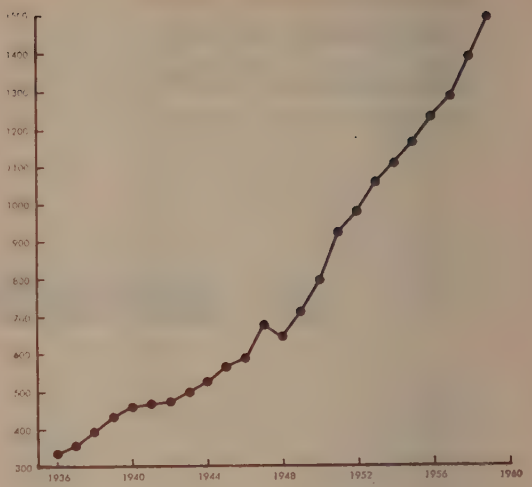

Figure 1—Total No. of Corporate Members of A.I.A.S. Since 1936

Status

It is rather more difficult to attempt an evaluation of the improvement in status of the profession in the eyes of the community over the 25 years, although there can be no question that the standing of our agricultural scientists in the world has increased materially. However, we can certainly say that present day farmers generally welcome a visit from our members, recognizing that science can give them considerable assistance. Governments and the general public also appreciate today the importance of the work of agricultural scientists whether as members of C.S.I.R.O., the universities or the State Departments of Agriculture. As an Institute we are getting greater recognition now from the Australian Agricultural Council and other bodies as a reasonably responsible group capable of speaking on behalf of the profession of agricultural science in Australia.

As indicated by Mr. Strickland in his contribution, our status as a profession has been considerably enhanced by the successful publication of the Journal of the Institute, followed by the request of the Australian Agricultural Council to publish a new national journal of experimental agriculture and animal husbandry. The establishment also of the Central Executive Office with staff and headquarters building has enabled the Insti-

TABLE 1

Corporate Members of the A.I.A.S. by States.

YEAR	N.S.W.	VIC.	Q'LD.	S.A.	W.A.	TAS.	A.C.T.	TOTAL
1936	83	73	40	51	41	17	25	331
1940	125	112	58	59	54	17	33	458
1947	185	167	66	79	72	24	48	675
1953	236	311	121	133	142	43	67	1,053
1959	371	446	198	138	168	60	106	1,487
% increase from 1936 to 1959	450	610	500	270	410	350	420	450

tute to bring to the notice of governments, national organizations, and private industry, the importance of the profession.

Professor H. C. Forster is Professor of Agriculture at the University of Melbourne. In 1955, while Assistant Executive Officer of C.S.I.R.O., Dr. Forster was Federal President of the Institute.

Employment

In 1957-58 a survey of the employment of members of the general profession of agricultural scientists was conducted by the Department of Labour and National Service. The results of this survey showed that the State Departments of Agriculture employ about half the agricultural scientists with the Commonwealth Public Services, chiefly C.S.I.R.O., about 19 per cent., industry 14 per cent., universities 10 per cent. and private farming 6 per cent. The major importance of the State Public Services in employment of agricultural science graduates has been amply stressed in the Institute publication *Agricultural Scientists in Australia.*

It is perhaps of rather more interest in this review to look at the trends of employment over the 25 years. Surveys of employment of members of the Institute have been made from time to time and Table 2 presents the numbers and percentages in the various branches up to 1958. Figure 2 illustrates more clearly the trends of the relative changes of employment. The figures agree reasonably well with the Department of Labour survey except that it would appear that an appreciable number of agricultural scientists in "industry" and in the "other" category are not members of the Institute with the result that the percentage of the profession as a whole in these two categories may be somewhat higher than in our Institute surveys.

State Public Service

Though the State Public Services have always employed the major proportion of members of the Institute, the overall percentage Australian figure has fallen from 63 per cent. in 1936 to 50 per cent. in 1947, at which approximate figure it has remained since. The drop in the 1958 figure to 45 per cent. has been due largely to the unexpected fall in the New South Wales figure. Since the Department of Labour survey showed a much higher figure, it would appear that a number of agricultural scientists in the New South Wales service are not now members of the Institute and that the true figure for the agricultural scientists employed in the State Services is very close to 50 per cent. It is of interest to note the wide range of State Government employment percentages in the various states in 1936 (92 per cent. in W.A. compared with 24 per cent. in S.A.) and that the difference between states has now been reduced materially. This has been due to the increase over the years of non-state employees in Western Australia and Tasmania and to the material increase of State employees in South Australia.

A more detailed analysis of the 1958 Department of Labour survey figures for State Public Service reveals the interesting fact that teachers in non-university education form an appreciable portion of agricultural scientists in the Service. Of the Australian State Public Service total 14 per cent. come in this class, with South Australia having the highest percentage at 23 per cent. It would appear probable that many of these are not enrolled with the Institute.

Commonwealth Public Service

The Commonwealth Public Services (including statutory authorities such as C.S.I.R.O.) are the next largest employing authorities. The Australian percentage figure rose from 13 per cent. in 1936 to 23 per cent. in 1947, and has been constant at about 19 per cent. since 1953. There is a wide disparity in numbers of Commonwealth Public Service members in the various branches, A.C.T. having a percentage ranging from 96 per cent. in 1936 to 91 per cent. in 1958, while membership in

TABLE 2

Employment of Members of the A.I.A.S. by States.

Members Employed in	Year	N.S.W. Nos.	%	Vic. Nos.	%	Q'land Nos.	%	S.A. Nos.	%	W.A. Nos.	%	Tas. Nos.	%	A.C.T. Nos.	%	Total Nos.	%
State Public Service	1936	62	75	44	67	20	71	11	24	24	92	14	82	1	4	176	63
	1940	83	69	67	59	37	71	19	31	37	70	17	94	—	—	260	58
	1947	93	54	77	50	44	75	26	37	49	69	18	86	—	—	307	50
	1953	119	50	136	46	60	54	55	50	72	59	23	70	—	—	554	52
	1958	115	39	203	49	92	53	54	44	94	61	37	64	1	1	596	45
Commonwealth Public Service	1936	2	2	4	6	2	7	9	20	—	—	3	18	24	96	36	13
	1940	8	7	15	13	6	11	15	25	2	4	1	6	30	97	77	17
	1947	31	18	25	16	6	10	19	27	5	7	2	9	55	98	143	23
	1953	33	14	43	15	22	20	22	20	15	12	5	15	59	95	199	19
	1958	48	16	46	11	33	19	19	15	16	10	7	12	86	91	255	19
Industry Including Banks	1936	10	12	8	13	1	4	2	4	—	—	—	—	—	—	21	8
	1940	14	11	18	16	1	2	—	—	1	2	—	—	—	—	34	8
	1947	17	10	29	19	1	2	5	7	4	6	1	5	—	—	60	10
	1953	28	12	58	20	4	4	6	5	6	5	3	9	—	—	105	10
	1958	41	14	79	19	11	6	6	5	11	7	3	5	—	—	151	12
Private Including Farming	1936	4	5	—	—	2	7	3	7	2	8	—	—	—	—	11	4
	1940	3	2	4	4	1	2	4	7	6	11	—	—	—	—	18	4
	1947	20	12	6	4	2	3	3	4	7	10	—	—	1	2	39	6
	1953	30	13	38	13	11	10	12	11	16	13	1	3	1	2	109	10
	1958	34	12	64	15	16	9	17	14	22	14	7	12	1	1	161	12
Universities	1936	5	6	7	11	3	11	20	45	—	—	—	—	—	—	35	13
	1940	12	10	9	8	7	13	23	38	7	13	—	—	—	—	58	13
	1947	18	10	13	8	5	8	16	23	6	8	—	—	—	—	58	9
	1953	21	9	12	4	12	11	14	13	12	10	1	3	—	—	72	7
	1958	43	15	17	4	14	8	24	20	11	7	2	3	3	3	114	9
Others Including Farming, Private Employment & Overseas	1936	4	5	—	—	2	7	3	7	2	8	—	—	—	—	11	4
	1940	4	3	4	4	1	2	4	7	6	11	—	—	1	3	20	4
	1947	25	15	9	6	3	5	3	7	7	10	—	—	1	2	50	8
	1953	37	16	44	15	13	12	13	12	17	14	1	3	3	5	128	12
	1958	48	16	73	17	24	14	20	16	23	15	9	15	5	5	202	15

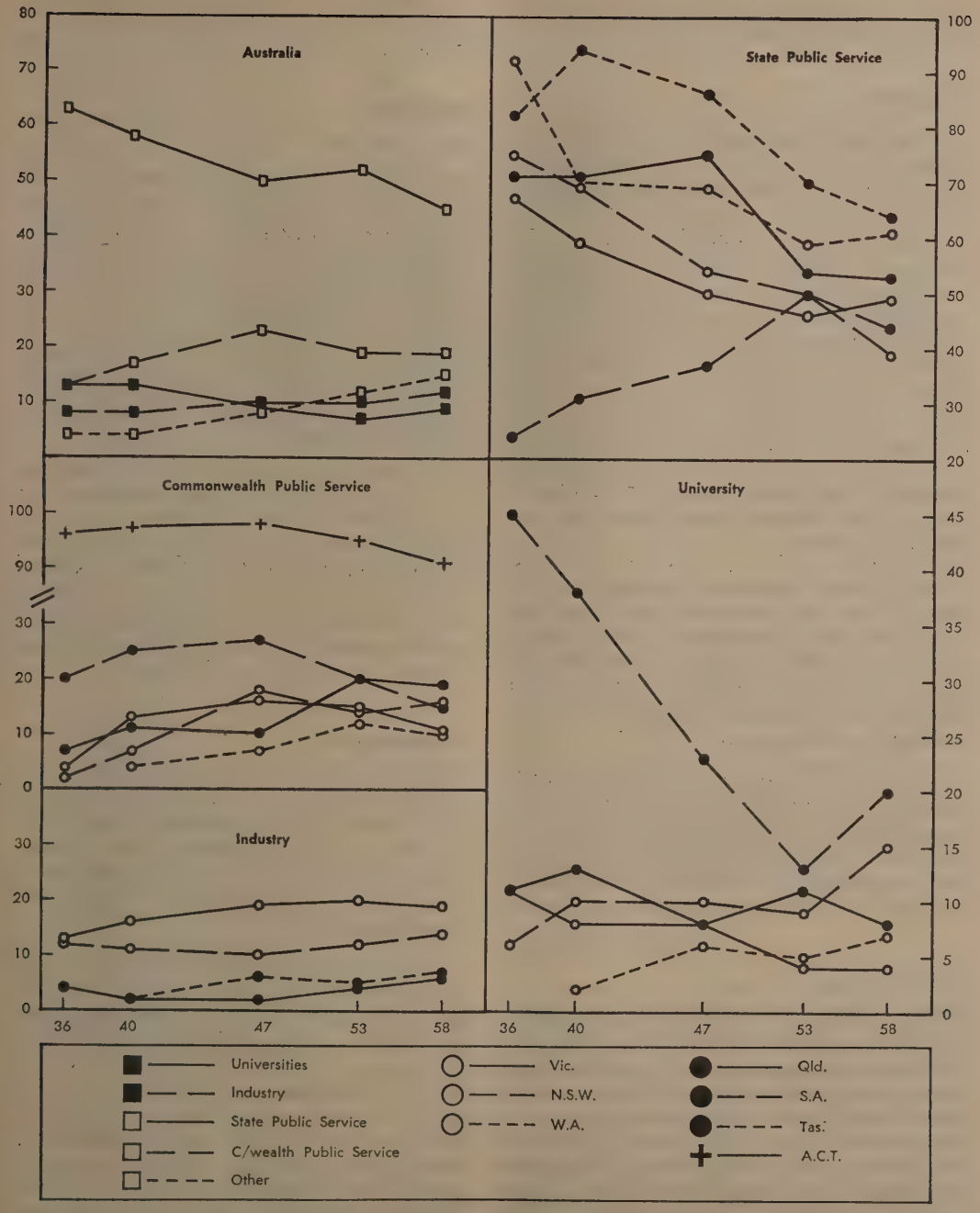

Figure 2—Trends in Employment of Members of the A.I.A.S. (Expressed in Percentages)

other branches ranged from 4 per cent. to 27 per cent. over the years.

Universities

Although the actual number of members employed at universities shows an increase over the years in all states except South Australia, the Australian percentage figure relative to the other employing authorities shows a decline from 13 per cent. in 1936 to 7 per cent. in 1953. The latest survey for 1958 shows a slight increase to 9 per cent. The drop in the percentage figures for Australia is undoubtedly influenced by the large fall in the South Australian figures. The mean figures for the three states, New South Wales, Queensland and Western Australia therefore form a better indication of average trends for university employment, and show a remarkably constant figure of about 10 per cent. over the 25 year period.

The figures for South Australia not only show a drop in percentage over the years from 1936 to 1953, but also a fall in actual numbers over these years. This has been due largely to the policy of the University of employing an increasing number of science graduates in those years.

Although Victoria followed the average trend in university employment up to 1947, percentage figures have fallen away since then and reflect the extremely low staff : student ratio characteristic of Melbourne University as a whole as recorded in the Murray Report.

Industry

Of material interest are the progressive figures for members employed in industry. The overall Australian figures show a gradual climb from 8 per cent. in 1936 to 12 per cent. in 1958. In Victoria the percentage figure has risen steadily from 13 per cent. in 1936 to the 1958 figure of 19 per cent. Somewhat surprisingly New South Wales with a large commercial industry has remained relatively constant through the years at about 10-14 per cent. As mentioned earlier, it is likely that the actual number of agricultural scientists employed in industry is higher than that shown in Table 2 and Figure 1.

TRAINING

The universities

Though the facilities, accommodation and courses of training provided in the Schools of Agriculture at our universities have improved during the past 25 years, much can still be done to make them more efficient. The Murray Committee Report has recently drawn attention to the present deficiencies in Agriculture in common with other faculties within the universities, and it is hoped that, with the support of Commonwealth finance, the situation will be improved.

In New South Wales, the situation has been eased somewhat by the addition of the new Faculties of Rural Science and Agricultural Economics at the University of New England, and the Faculty of Animal Production at the University of Sydney. The initiation of an agricultural faculty in the University of Tasmania should provide much needed facilities for training in that state.

Undergraduate

Undergraduate courses at the universities have altered materially over the years. With the rapid extension of knowledge in the older sciences and the development of new fields in agriculture, courses have so multiplied in number that the student runs a real risk of mental indigestion.

Some faculties have looked for the solution of this problem in specialisation at the third and fourth years as in the case of Sydney and Adelaide, while others have adhered to a more restricted basic general course for the four undergraduate years leaving specialisation to the postgraduate years. Much can be said in support of each type of teaching; the former will undoubtedly produce a more intensively trained man in the particular specialisation, but for the general average student who may have a limited choice of positions offering on graduation, the broader basic training may have more appeal. The Univer-

sity of Sydney has introduced a further alternative of a three year course (B.Ag.) based on the broad training given in the first three years of the normal four year course.

Many new fields have been introduced or strengthened in the agricultural faculties since 1935. Two such avenues viz., animal husbandry and agricultural economics are now major subjects in most states, and in some universities have been promoted to separate faculties in recognition of the important part that these sciences are now playing in agriculture. Following a report on the importance of agricultural engineering to the agricultural profession prepared by the Institute, a separate degree course in Agricultural Engineering has been initiated at the University of Melbourne, and research activities stepped up at the Universities of Melbourne and New South Wales.

Specialist training for extension advisory services is somewhat belatedly receiving more recognition, together with the broader subject of rural sociology as the appropriate science to deal with the farmer himself as a unit of the rural community.

Postgraduate

The strengthening of postgraduate schools and research in all agricultural faculties has been assisted materially by additional finance now provided outside State University grants, including the Commonwealth Reserve Bank Rural Credits Fund, the various primary industry research trusts and more recently still the Commonwealth Government University grants. Recognition by the authorities of the vital part that a strong postgraduate teaching and research unit plays in promoting a live faculty has been too long delayed.

CONDITIONS OF EMPLOYMENT

Salaries

The recent Institute report *Agricultural Scientists in Australia* sets out in some detail the present salary status of members of the profession. In the 25 years since 1935, money values have altered materially with inflation, and direct comparisons give no indication of relative positions in terms of real values.

Initial starting salaries for new graduates in the Victorian State Public Service were approximately £300 in 1935 compared with the figure of about £1,400 in 1959. After allowing, on the basis of the C series index, for the change in money value of the pound (the 1935 £1 being equal to a 1959 value of 6s. 2d.) it would appear that the comparative level of salaries has improved. Similarly, in the case of salaries of senior administrative officers, the level has risen although not by so much. The recent margins adjustment of 1960 will raise salaries still higher, although this may possibly be offset by a further fall in the purchasing power of the pound.

Considerable attention has been drawn to the results of a survey conducted in 1956 by the Appointments Board of the University of Melbourne which showed that agricultural scientists received, with physicists, the lowest mean income of the nine professions examined. This state of affairs cannot be viewed with any degree of satisfaction as, apart from other considerations, it must have a detrimental effect on the calibre of the students attracted to the profession. However, the results must be treated with some caution since due allowance must be made for the particular benefits which apply to some employer categories and which are not assessed in a straight salary scale.

Facilities for training

Opportunities for students to undertake university studies have improved greatly over the 25 years. Commonwealth Government Scholarships, and cadetships by government departments and private industry, supplemented frequently with material financial support for the individual during his student days, ease the burden during the period of training. For the more gifted individuals who will be our future research officers, facilities for postgraduate scholarships are also more freely available. Recognition that postgraduate training at the university is just as

essential for the research man as his undergraduate work is a marked advance on the 1935 approach to this problem. It is of particular importance that we should develop high grade postgraduate schools at specific centres in Australia in view of the difficulty of getting any material number of our men to overseas centres.

For the agricultural scientist who has restricted opportunity to keep abreast with modern knowledge, the Institute in conjunction with the departments and the universities has taken an active part in recent years in conducting Refresher Schools where recent advances in scientific outlook and information can be presented in a concise form.

The more advanced specialist has equally been served by a number of specialist technical conferences which not only permit officers to come together from widely separated parts of the Commonwealth, but also facilitate intimate discussion on problems of common interest.

More recently, attention has also been given to the more difficult though none the less urgent problem of bringing together the research worker and the extension advisory officer. These conferences have not only permitted the research man to tell of his latest information, but they have also enabled the advisory officer to present the local problem so that together they can work out a practical solution to the farmer's difficulties. A welcome addition to an increasing number of such conferences has been the farmer himself.

Conditions and facilities for work for agricultural scientists in government departments and elsewhere have also improved appreciably. In the present day world, aids in the way of modern scientific laboratory instruments and up-to-date mechanised field equipment can reduce the time-consuming, laborious, and often routine operations, materially, and with provision of efficient technical assistance can result in more efficient use of the scientist's time. The old days when it was considered good for the scientist to do his own bottle washing or weeding of his field plots, are happily gone.

WHAT OF THE FUTURE?

This review of the progress over the past 25 years opened with a challenge—what part can agricultural scientists and the Institute play in meeting the problems of the future? May I suggest one or two of the more urgent problems.

● From the scientific point of view, agricultural scientists in the past have tended to make their contribution primarily as specialists—as soil chemists or physicists, as crop or pasture experts, as animal physiologists, biochemists or nutritionists. One of the important contributions that agricultural scientists, with their broad training, can make increasingly in the future is in looking more closely at the interactions, not only between soil, plant and animal, but also the interaction between agricultural economics and crop and animal production, and in promoting the closer co-operation of sociologists, economists and advisory officers. Agricultural science equally with biology can be defined as the science of interactions.

● The Institute has stressed in recent years the importance of the extension officer in overcoming the delay in applying research findings to agricultural practice. There are several aspects of this problem which await solution.

Too often research information is not directly applicable to farm practice. Our present research stations are well adapted to test the field application of research findings, but they do not attempt the difficult task of incorporating the new finding into farm practice and management, nor do they really look at its economic implications. Usually this is left to the more enterprising farmer who can probably only afford to arrive at the ideal solution by the slow process of trial and error.

The advisory services of the Departments of Agriculture attract many good men, but too often these are lured away from a district just when they have reached their most productive period. This may be caused partly by a scarcity of agricultural scientists, but in many cases the problem goes deeper than

that. Opportunity for advancement in a district is never as good as at Head Office.

Much of the success of a good district advisory service lies in the development of a team spirit between a group of officers responsible to a regional head, each contributing in their own particular field and working on a common problem to a common goal. The value of decentralised regional services has been appreciated by administrators in the several states of the Commonwealth as well as in the United Kingdom. The New South Wales Department has recently initiated several such centres in that state, but time alone will tell whether we have solved the problem of the conflict between centralized divisions and decentralized regional control.

● Recent surveys by the Department of Labour and National Service indicate that we must face in the immediate future a material increase in the numbers of young people wishing to enrol for university training. Estimates prepared in 1957 for the Murray Committee of the numbers of future undergraduates are already well below actual numbers. The latest statement by the Secretary of that Department puts the increase, on the basis of population alone, at a figure of 27 per cent. by 1963, and 45 per cent. by 1965, taking 1958 as a base year. With the additional increase, which will result from the desire of a greater percentage of students to undertake tertiary education, the figures for estimated increases are 51 per cent. by 1963 and 78 per cent. by 1965.

The initial problem then is one of providing accommodation at our university schools of agriculture for these expected numbers of students. New South Wales has indeed planned well in establishing a fully equipped second centre at Armidale, but the position in Victoria, with only one school of agriculture, gives cause for considerable alarm. Provision has been made in the proposals for the coming triennium for expansion of the School of Agriculture at Melbourne, but a second decentralized school is desirable. It is likely that the new university at Monash will have its hands more than full with its present commitments for some time to come and thought must be given to the question as to whether the development of a rural university, as in the case of Armidale, is the best move. The situation in the other states with smaller numbers of students does not appear to be so serious, but undoubtedly provision for additional accommodation will be necessary.

● A further problem concerns the future employment of agricultural scientists on graduation. The Institute survey in taking account of departmental, university and industry needs has rightly taken a cautious outlook on future employment, but the authors stressed that their analysis has been based on averages of the past. As they stated, they measured "present effective demand but grossly understate the future need for agricultural scientists". Moreover, they added that their appraisal had not taken into account the very great demand for graduates to undertake the new programmes of research to be financed by the levies now agreed to by the wheat, dairy and beef cattle producing primary industries. It is essential that we review the position frequently.

● Serious thought must be given by the profession, in the near future, to the problem of the private agricultural consultant. The advisory services that can be provided by the government are not likely to be able to meet the greatly expanded demand of the future. The experience of our sister institute in Canada should serve as a reminder that we should plan for the growth of this type of agricultural scientist.

CONCLUSION

In reviewing our progress as a profession, I believe we can say with every justification that we have gone a long way over the past 25 years in meeting the goal set for us by the first President of the Institute. We have certainly developed an esprit de corps in the profession as a whole without in any way sacrificing healthy argument between our members, and public opinion now recognises the importance of the scientific approach to agri-

cultural production. A visitor from overseas once commented to me that, in his view, agricultural science as a profession receives greater recognition in Australia than it does in any other country in the world.

The general pattern of employment of agricultural scientists in this country is now becoming fairly clear although it is likely that in the fields of industry and private consultants, there may be opportunity for greater proportionate expansion than in the present more popular avenues of employment.

The Institute might well continue therefore to review at frequent intervals the likely opportunity for graduates in the respective fields. As a particular demand develops they can frame their recruitment policy accordingly remembering always that it may be some five or six years from the time of any decision before any material increase in graduates can be obtained.

The profession as a whole can play a more important part, not only in planning the broader problems of agricultural development in Australia and the specific training of agricultural scientists to meet the needs of the country, but also in improving the many more minor aspects associated with terms and conditions of employment of our present members.

Finally, may I stress the challenge, that must be of increasing importance, that Australia should play a major part in aiding the countries of South-east Asia to improve their standards of agricultural production. In their case, the need is for Australian men to give technical advice and service to their producers, accompanied by the training of their young men in our universities and Departments of Agriculture. Here surely is a problem which could well be more important than any other if we are to maintain peace in the world of tomorrow.

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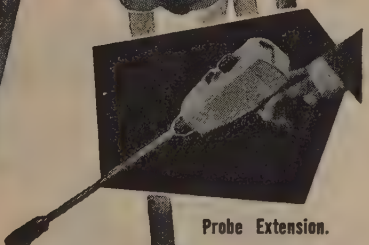

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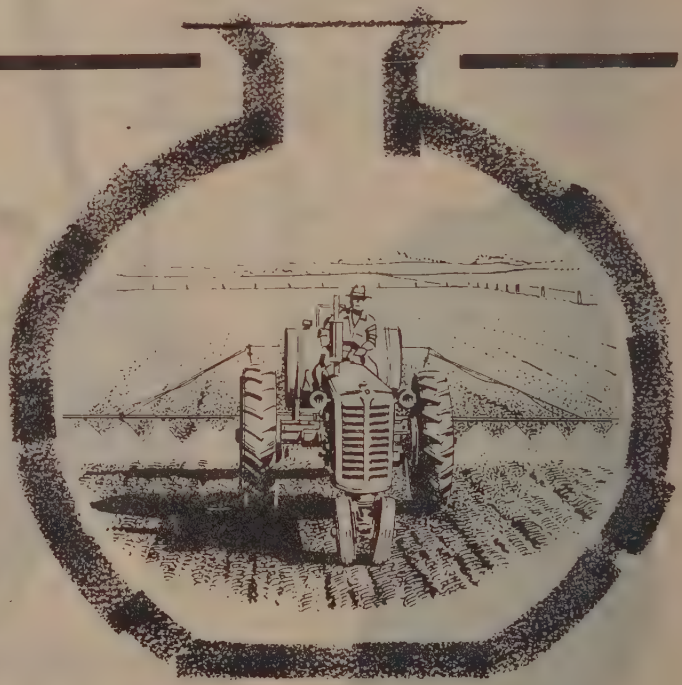

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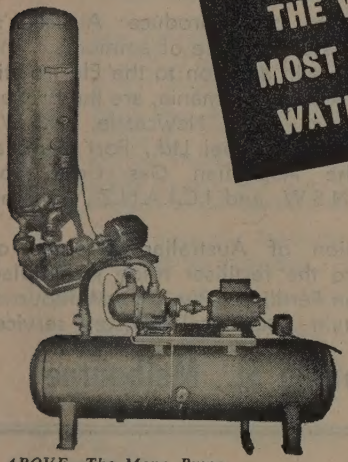

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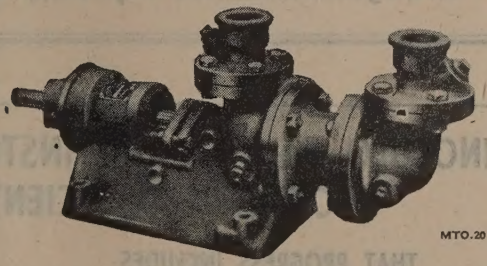

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Assistance from industry 1956	£4,022/5/0	from 45 organisations.
Assistance from industry 1957	£3,980/10/0	from 50 organisations.
Assistance from industry 1958	£3,621/1/0	from 52 organisations.
Assistance from industry 1959	£3,976/8/0	from 67 organisations.

Donations for 1960 are gratefully acknowledged from:

Commonwealth Fert. & Chem. Ltd.	£75	Fifth annual contribution.
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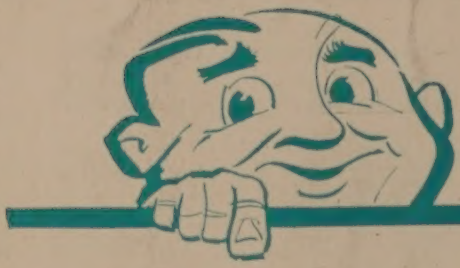

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